Fertility of Salmonoid Eggs and Sperm after Storage

By I. Barrett

Department of Zoology, University of British Columbia
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ABSTRACT

The effects of storage on the fertility of salmonoid eggs and sperm have been studied. In these experiments mature eggs and sperm were stripped into dry sterile jars and stored for varying periods at low temperatures before testing their fertility with fresh genital products. The methods have been used and found to be feasible under field conditions. Eggs of the chum salmon, *Oncorhynchus keta*, were stored at temperatures of 2.5° to 5.8°C. for 108 hours with an average infertility of less than 20%. The sperm of this species show a wide variation in their reaction to storage but may be retained for 36 hours in sterile jars with an average of less than 10% infertility. Data for the Kamloops (*Salmo gairdnerii Kamloops*) and cutthroat (*Salmo clarkii lewisi*) trout are confirmatory. Preliminary experiments indicate the feasibility of transporting eggs and sperm stored together in the absence of water.

INTRODUCTION

One of the difficulties commonly experienced in fish cultural operations is the shortage of either male or female fish at some time during the spawning run. A method of storing eggs and sperm without high mortality, rather than holding the fish in pens, would appear to be advantageous. Difficulty also occurs where collections are made at points distant from hatcheries and the fertilized eggs must be transported long distances. This procedure may be rather inefficient due to the fragility of the recently fertilized egg and since it poses such difficulties as temperature and oxygen control, the prevention of agitation, and the physical problem of transportation.

The risk of transporting green (newly fertilized) eggs may be avoided by allowing the eggs to develop at local "eyeing stations". When "eyed", the eggs are shipped, usually with small losses, to a central hatchery, where they are hatched and reared. Holding the eggs at field "eyeing stations" until they are "eyed" often involves the maintenance of hatchery crews for an extra 4 to 6 weeks. The advantage of transporting the eggs and sperm, as soon as they are taken, to the central hatcheries rather than holding the eggs until they are "eyed" is indicated. That these difficulties might be minimized by transporting the less fragile unfertilized eggs and sperm in an appropriate manner to the hatchery and then completing the fertilization is indicated by this study.

The viability of the eggs and sperm of fishes, especially salmonoid fishes, has aroused some attention from fish culturists since the middle of the nineteenth century. Vrasski (Soudakevicz, 1874) in Russia in 1854 was probably the first person to store fish milt. He was able to use successfully the milt of *Acerina*

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vulgaris after it had been held in a dry vial for 6 days. Atkins (1874), working in New England on the Atlantic salmon (*Salmo salar*) held eggs and sperm for periods up to 4 days with resultant mortalities ranging from 0 to 100%. Rutter (1902) in California concluded that the genital products of the spring salmon held in the dead fish for less than 5 hours may safely be used for fish cultural purposes. Nakano and Nozawa (1925), in preservation experiments with the eggs and sperm of the Japanese salmon (*Oncorhynchus masou*), used with good results eggs and sperm that had been stored for 97 hours at a temperature range of 5.3° to 13.0°C. More recently, Smith and Quistorff (1943), in the State of Washington, stored milt of both the steelhead and spring salmon in full sealed vials at a temperature range of 6.7° to 7.0°C. and concluded that spring salmon milt may be held up to 5 hours with less than 10% mortality.

MATERIALS AND METHODS

Experiments on the storage of the genital products of three species of British Columbia fish were performed during 1948 and 1949. Species studied were the chum salmon, *Oncorhynchus keta*; the Kamloops trout, *Salmo gairdnerii Kamloops*; and the Yellowstone cutthroat trout, *Salmo clarkii lewisi*. The basic plan followed in this series of experiments was the stripping of mature roe and milt into dry sterile vessels, the storing of these containers at a low temperature and the subsequent fertilization of this stored spawn in order to determine the resultant mortality. Controls were run in all cases.

Chum Salmon Experiments

Experiments were carried out, November 19 to 28, 1948, at the Provincial Trout Hatchery, Cultus lake, B.C. The eggs and sperm were stored for multiples of 12 hours up to 192 hours (8 days) in containers held at 2.5° to 5.8°C. and were then employed in the usual artificial fertilization procedure. Four fish, 2 males and 2 females, were used for each time period. The eggs or sperm from each fish were divided into 2 storage lots, making a total of 8 samples for each period. The eggs were held in dry, sterile, wide-mouth pint jars, which could be tightly sealed; the sperm in dry, sterile, 2-ounce (60 ml.) screw-cap jars.

The procedure for storage was as follows: After bleeding the mature female fish and wiping it dry with towelling, eggs were taken by the incision method directly into two storage jars. This method practically eliminated contamination of the sample by immature or broken eggs or by water, blood and excreta. With the eggs came some coelomic fluid so that the eggs were kept moist at all times. Approximately 800 eggs were taken in each of two jars.

In addition to the two samples of eggs taken for storage from each fish, two smaller lots of about 200 eggs each were also procured. One lot was placed unfertilized in the hatchery trough to serve as a point of reference for any unfertilized eggs in the experimental lots, while the second was fertilized with milt from the male whose milt was to be stored for the same time period as the eggs in question. This second served as a control.

The milt was stripped from stunned, dried male salmon into two sterile 2-ounce jars. Approximately 5 ml. of milt were held in each jar.

The sealed jars of milt and eggs were placed in an ordinary wooden icebox for the appropriate storage period. The fertilized and unfertilized control lots of eggs were placed in trays in the hatchery troughs. After 24 hours' incubation, these eggs were taken from the troughs and preserved in Davidson's fluid, for subsequent examination.

After a suitable storage period, the unfertilized eggs were taken from the icebox, fertilized with fresh milt and placed in the troughs for 24 hours. The stored milt was used to fertilize freshly stripped eggs and these, too, were placed in the troughs for 24 hours. The fresh eggs fertilized by the fresh milt, in each case, served as controls.

Thirty-two males and 32 females were used as the source of the experimental sperm and eggs. One hundred and twenty-eight samples in all were held in the iceboxes, over a period of 192 hours.

Fertilization was determined by microscopic examination of the germinal disc which was exposed by removal of the chorion. If the eggs had been fertilized, the first to fourth cleavages were plainly visible on the germinal disc. If fertilization had not occurred, there was no evidence of cleavage on the disc, which then appeared as a white, unmarked button. The number of unfertilized eggs present in a 200-egg lot of each sample was determined.

KAMLOOPS TROUT EXPERIMENT

This work was performed at the Provincial Trout Hatchery at Gerrard, B.C., from May 12 to August 18, 1949. For this experiment the eggs from 3 mature trout, stripped by the expression method on May 12, were used. The eggs were taken rather late in the spawning season and both the parents and eggs were in only fair condition. The eggs from each female were divided into 4 approximately equal lots, making a total of 12 lots. One lot from each of the 3 fish was fertilized immediately and served as a control. The remaining 3 lots from each were stripped into sterile, dry, 500 ml. wide-mouth mason jars. The jars contained 250 to 300 eggs each and were about one-sixth full. Care was taken that no water entered the jars. The jars were then tightly sealed and held in an icebox at a temperature range of 1.5° to 4.0°C. After 2 days' storage, 1 lot of eggs from each fish (3 lots in all) was fertilized with fresh milt and placed in a hatchery trough. Another series was fertilized after 4 days of storage and the last after 7 days.

Dead eggs were removed regularly from the baskets and examined under the dissecting microscope for evidences of cleavage. Hatching commenced on June 22. As the trout started to feed, they were given the regular hatchery diet of curds and liver. The 12 lots were killed on August 18, and tallied. A total of 2,962 eggs was used.

An experiment was run simultaneously at Gerrard with 477 eggs of a fourth trout. As a matter of interest, these eggs were sealed in a sterile mason jar and

held at 5.5°C. for 2 days. In addition to the storage, the eggs were subjected to constant agitation, so that they were kept moving about within the storage container.

CUTTHROAT TROUT EXPERIMENT

A preliminary experiment on the transportation at low temperatures of unfertilized eggs and sperm was conducted on July 2, 1949 at lake Magog, B.C., and Cranbrook, B.C. The fish used was the Yellowstone cutthroat trout, taken during the spawning migration from a temporary trap on the lake's inlet stream. Approximately 10,000 eggs from 25 ripe females were stripped by the expression method into 6 sterile, dry, 500 ml. wide-mouth mason jars. Each jar was three-quarters full and held about 1,600 eggs. Milt from 35 males was stripped into 14 sterile, dry vials, fitted with corks. To 1 of the 6 jars of eggs was added milt from 3 males. As a control lot, 3,000 eggs were fertilized, hardened and packed in trays, at lake Magog. The experimental jars and vials were tightly sealed to prevent the entrance of water. They were then placed in a pack-box with an ice-moss mixture at a temperature range of 4° to 8°C. The trays of fertilized eggs were placed in a second pack-box, also with an ice-moss mixture. The samples were taken by packhorse from lake Magog to the main highway, a distance of 27 miles. This trip lasted 8 hours, during which time the samples were subjected to considerable agitation. The pack-boxes were taken by truck to the Cranbrook Hatchery, a six-hour trip. On arrival at the hatchery, the fertilized eggs in the trays were placed in the troughs. Also, the eggs in one jar were fertilized with the milt from two vials and placed in the troughs. The remainder of the vessels were left in the ice-moss mixture. Jars of eggs were then fertilized at 24, 36, 48 and 60 hours storage after stripping. Four, rather than 2, vials of milt were used for each of the two last samples. In the last two jars, precipitated material after the addition of water indicated the presence of broken eggs.

Water was added to the jar containing both eggs and milt, after 24 hours of storage, completing the fertilization programme.

After each lot had incubated for 24 hours, a sample of 100 eggs was examined for evidences of cleavage, and the per cent mortality determined.

RESULTS

CHUM SALMON EXPERIMENTS

In figs. 1 and 2 the percentages of unfertilized eggs have been plotted against the period of storage for eggs and sperm respectively. Each point represents one sample at that particular time period. The numbers adjacent to some of the points indicate the number of times that particular percentage is represented on the graph at that time period. A trend line for each graph was plotted by a moving average of threes.

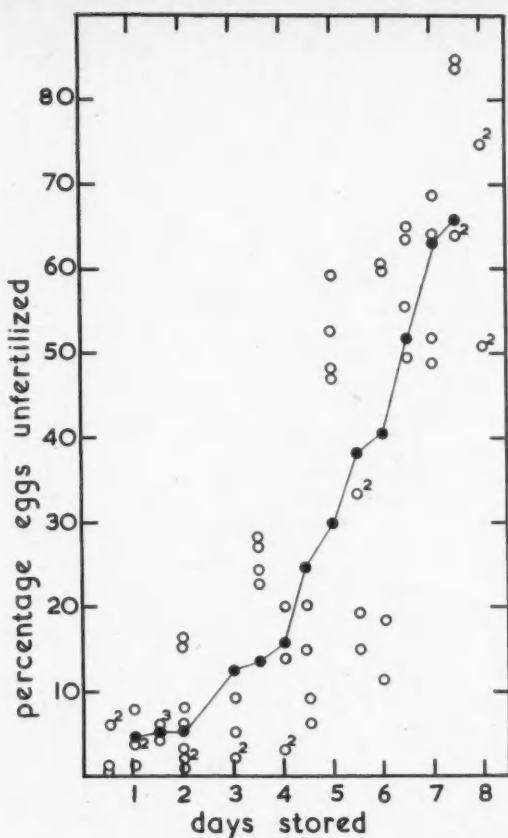The average loss in the control lots was less than 2 per cent.

FIGURE 1.   Effect of storage on the fertilizability of chum salmon eggs;
stored eggs fertilized with fresh milt.

KAMLOOPS TROUT EXPERIMENT

The Gerrard data are presented in table I.   Both the numbers of unfertilized eggs and the total mortality until August 18 are given.   In the last line, the per cent mortalities from the 3 fish for each period have been averaged.   It is believed that the high mortality in the controls (average 35.6%) was due to the overripe condition of the females.

The only abnormal fish found were in both the control and the seven-day storage lot of fish No. 3.   The former had 3 double-headed fish and the latter had 1.

The mortality of the eggs kept in motion for 2 days prior to fertilization was 42/477 eggs, or 8.8%.
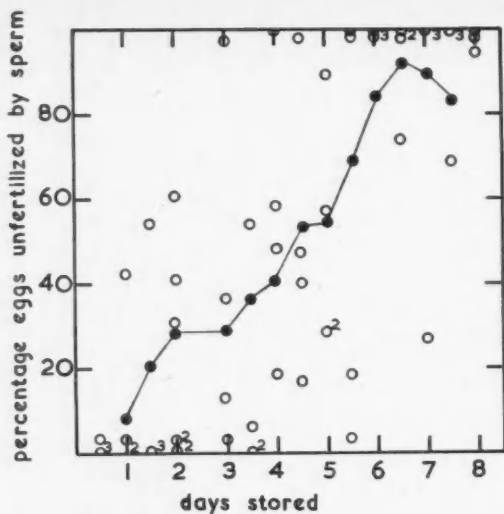
FIGURE 2. Effect of storage on the fertilizing ability of chum salmon sperm; stored sperm added to fresh eggs.

CUTTHROAT TROUT

The infertility of the control eggs fertilized and hardened at lake Magog was 8%. The eggs to which milt had been added at lake Magog and water at Cranbrook showed an infertility of 1%. The data for the remaining experiments are summarized in table II and are self-explanatory.

DISCUSSION

Fig. 1 shows a definite relationship between the length of storage and the fertility of stored eggs. As the trend line indicates, however, the relationship is not a precise one. It is evident that the eggs of the chum salmon may be stored for 72 hours, under the conditions of this experiment, with less than 10% infertility, in 22 of 24 cases. Storage of the eggs for 108 hours resulted in less than 20% infertility in 32 of 36 cases. After 108 hours storage, the percentage of infertile eggs rapidly rose to a maximum of 85% after 8 days.

The data plotted in fig. 2 indicate a wide range of mortalities in the stored milt samples. Up to 36 hours storage, 10 of 12 samples stored had less than 5% infertility. From 0 to 96 hours storage, 24 of 32 samples had less than 50% infertilities, the mean being 8.9%. From 96 to 192 hours, 24 of 32 samples showed infertilities above 50%. The data are erratic with, for example, an infertility of 99% resulting in one case after only 48 hours storage, while a 192 hour storage of another sample resulted in no infertilities. Several factors, such as physiological differences between the sperm samples, variation in maturity

TABLE I. Percentages of unfertilized eggs and mortality of eggs of
Kamloops trout stored at Gerrard, B.C.

		Control Fert. May 12	2 Day Storage Fert. May 14	4 Day Storage Fert. May 16	7 Day Storage Fert. May 19
F I S H No. 1	Total eggs in sample	278	332	236	401
	Number unfertilized	58	142	59	128
	% unfertilized	20.8	42.8	25.0	31.9
	Total mortality to Aug. 18	65	154	72	240
	Total % mortality	23.2	46.3	30.5	60.0
F I S H No. 2	Total eggs in sample	253	316	175	224
	Number unfertilized	128	43	63	86
	% unfertilized	50.6	13.6	36.0	43.3
	Total mortality to Aug. 18	134	52	68	97
	Total % mortality	53.0	16.4	38.8	38.3
F I S H No. 3	Total eggs in sample	228	165	198	229
	Number unfertilized	55	79	118	87
	% unfertilized	24.1	46.7	59.6	37.5
	Total mortality to Aug. 18	70	103	142	130
	Total % mortality	30.7	62.4	71.2	58.7
Average Total % Mortality		35.6	41.7	46.8	51.7

TABLE II. Percentage infertility of cutthroat trout eggs
collected at lake Magog and transported to storage at
Cranbrook, B.C.; one jar eggs for each storage period.

Hours stored	Vials milt used per jar eggs	% infertile
16	2	6
24	2	41
36	2	18
48	4	100
60	4	100

of parent fish, slight experimental variation in the technique of storage, entrance of moisture into the storage vessels, oxygen supply and carbon dioxide removal may be held to account for this diversity. All or none of these factors may have been operative.

From the practical point of view, sperm may be stored with a low mortality for at least 36 hours. Beyond this time, if the sperm were to be held under the conditions specified, it would probably be wiser to store several samples in the hope that one or two of these samples would show a high fertility. Further investigation will undoubtedly remove this aspect of uncertainty.

In table I, the relatively high percentage of mortality in the control lots of eggs held at Gerrard may be explained by the lateness of the spawning season and the poor condition of the parent fish. With an average loss of 35.6% in the controls, an average loss of only 51.7% resulted after storage of the eggs for 7 days.

The results of the Magog experiment, given in table II, are interesting in that after 16 hours of rough transportation and 20 hours of storage for both the eggs and sperm, an infertility of only 18% resulted. It is interesting that in fish cultural practices today, transporting newly fertilized eggs for longer than 24 hours, even under the best conditions, is considered inadvisable.

For the 48 and 60 hour samples, it is not possible to label definitely either the death of the eggs or of the sperm as the cause of the 100% infertility. The losses would appear to be due to the presence of broken eggs in the storage jars, rather than to any deaths in the sex cells. This emphasizes the necessity for care in stripping the fish.

The 99% fertility after 24 hours storage of the mixed sperm and eggs is of particular significance and warrants further investigation. If the method proved itself, it would have advantages over the separate storage of the eggs and milt both as a simplification in technique and as an advance in the methods of maintaining the viability of the sperm.

From the above, it is evident that both the eggs and sperm of at least 3 species of salmonoid fish may be held in an unfertilized state for some length of time with a low mortality. To the fish culturist and hatchery man, the knowledge of what can be done with eggs and sperm under certain conditions should do much to solve his problems of fish shortages and transportation.

SUMMARY AND CONCLUSIONS

1. A field technique has been developed for storing salmonoid eggs and sperm for varying periods prior to fertilization.

2. The eggs of *O. keta* may be stored in sterile jars at a low temperature for 108 hours with an average infertility of less than 20%.

3. The sperm of *O. keta* may be stored up to 36 hours in sterile jars in the absence of water and at a low temperature with an average of less than 10% infertility.

4. The sperm of *O. keta* are less successfully stored than the eggs and show a wide variation in their reaction to storage.

5. The data for the *S. gairdnerii kamloops* eggs indicate that results similar to those for *O. keta* eggs may be obtained if the eggs are initially in good condition.

6. The results of the storage of the *S. clarkii lewisi* eggs and sperm tend to confirm the applicability of this technique.

7. The variation in technique, whereby both the eggs and sperm are stored together in the absence of water, warrants further investigation.

ACKNOWLEDGEMENTS

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Pelagic Amphipoda of the Belle Isle Strait Region

By E. L. Bousfield

Fisheries Research Board of Canada
and
Department of Zoology, University of Toronto
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ABSTRACT

The distribution of certain pelagic Amphipoda taken in the Belle Isle strait region during the summer of 1923 is correlated with ocean currents, light intensity and size of individuals. *Hyperoche medusarum, Themisto libellula* and *Pseudalibrotus glacialis* are index species of the cold Labrador current in the area. *Hyperia galba* and *H. medusarum* are presumably also cold water indicators. *Themisto abyssorum* in sizeable numbers, and *Calliopius laeviusculus* are related to waters of the gulf of St. Lawrence. *Themisto libellula, T. compressa* form *compressa* and *T. compressa* form *bispinosa* are more numerous, while *T. abyssorum* is less numerous at the surface during daylight than during darkness. Part of the breeding season of *T. compressa* and *T. abyssorum* occurs in the area during August and September, when the young of both species are much more numerous than the adults, particularly at the surface. A new southern limit of distribution for *P. glacialis* is established. The known distribution of the tropical genus *Phronima* is extended into the gulf of St. Lawrence.

INTRODUCTION

During the summer of 1923, an oceanographic expedition of the Canadian Department of Marine and Fisheries under the direction of Dr. A. G. Huntsman, biologist to the Biological Board of Canada, was carried out in the waters around Newfoundland by the Fisheries cruiser "Arleux" and the Biological Board motorboat "Prince". Some of the results of this expedition have been worked up by previous investigators in explaining the complex circulation of these waters in the Belle Isle strait region.

In general, the nature of the water in Belle Isle strait is determined by two ocean currents. The Labrador current, originating in Davis strait and consisting of very cold ice-laden water, sweeps southward along the east coast of Labrador and Newfoundland, carrying with it a typically arctic fauna. A branch of the current invades the strait at its eastern end, passing inward chiefly on the north side. It continues thence along the north and west coast of the Esquiman channel, around cape Whittle, and becomes dissipated southward in the comparatively warm surface waters of the gulf of St. Lawrence. The winter flow is largely responsible for the ice-cold layer of gulf water between 25 and 150 metres deep throughout the summer (Huntsman, 1925). The surface waters of the gulf

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of St. Lawrence, with temperatures between 10° and 12°C., and likewise carrying typical fauna, are driven by prevailing southwesterly winds of summer toward the inner end of the strait of Belle Isle. The current set up passes outward mainly along the south side of the strait, mixing with the incoming Labrador current to a greater or less degree, depending on meteorological conditions. The forces maintaining the water circulation in Belle Isle strait have been discussed by Huntsman (1925).

The warm water of the gulf of St. Lawrence passes seaward between Belle isle and cape Bauld and thence flows southward along the east coast of Newfoundland where it is transformed considerably by the greater quantity of colder water of the Labrador current proper. This mixed coastal water is believed *not* to penetrate the bays of the east coast (Pinhey, 1926). The main body of the Labrador current passes around cape Freels and ultimately mixes with the tropical gulf stream over the Grand banks of Newfoundland.

MATERIAL AND METHODS

The material used in this investigation was collected by a no. 0 (bolting cloth) net in tows of 15 minutes' duration (unless otherwise noted) and will be referred to as no. 0 material. Horizontal tows were taken at the surface (within the first metre or so) and at a depth of 20 to 30 metres at most of the "Arleux" and

TABLE I

| Stations	Numbers	Date	Locality
"Prince"	427-432	July 30-31	Barbace point to Mistanoque island
"Prince"	412-408	Aug. 7	Savage cove to Amour point
"Arleux"	12-15	Aug. 11-12	Heath cape to Fog island, Que.
"Arleux"	16-19	Aug. 12	Fog island to bay of Islands
"Arleux"	20-22	Aug. 15	Bay of Islands to Fish harbour
"Arleux"	23-30	Aug. 15-16	Flat island to Ferolle point
"Arleux"	30-35	Aug. 16	Ferolle point to Greenly island
"Prince"	426, 439	Aug. 16, 17	Chateau bay
"Arleux"	37, 39, 93	Aug. 17	Forteau bay to Savage cove
"Arleux"	44	Aug. 17	Off Watt's bight
"Arleux"	45-52	Aug. 18-19	Double island N.E. into Atlantic
"Arleux"	54	Aug. 21	West of cape Norman
"Arleux"	55, 57	Aug. 21	Flower point to Blanc Sablon
"Arleux"	59	Aug. 31	Bay of Islands
"Arleux"	60	Sept. 1	Off Rich point
"Prince"	408-412	Sept. 7	Savage cove to Amour point
"Arleux"	64-68	Sept. 6	Cape Norman to Wreck bay
"Arleux"	69-72	Sept. 7	Chateau bay to Belle isle
"Arleux"	73-78	Sept. 7	Belle isle to cape Bauld
"Arleux"	80-93	Sept. 9-14	East coast of Newfoundland
"Prince"	448, 451	Sept. 10, 15	Bradore bay region
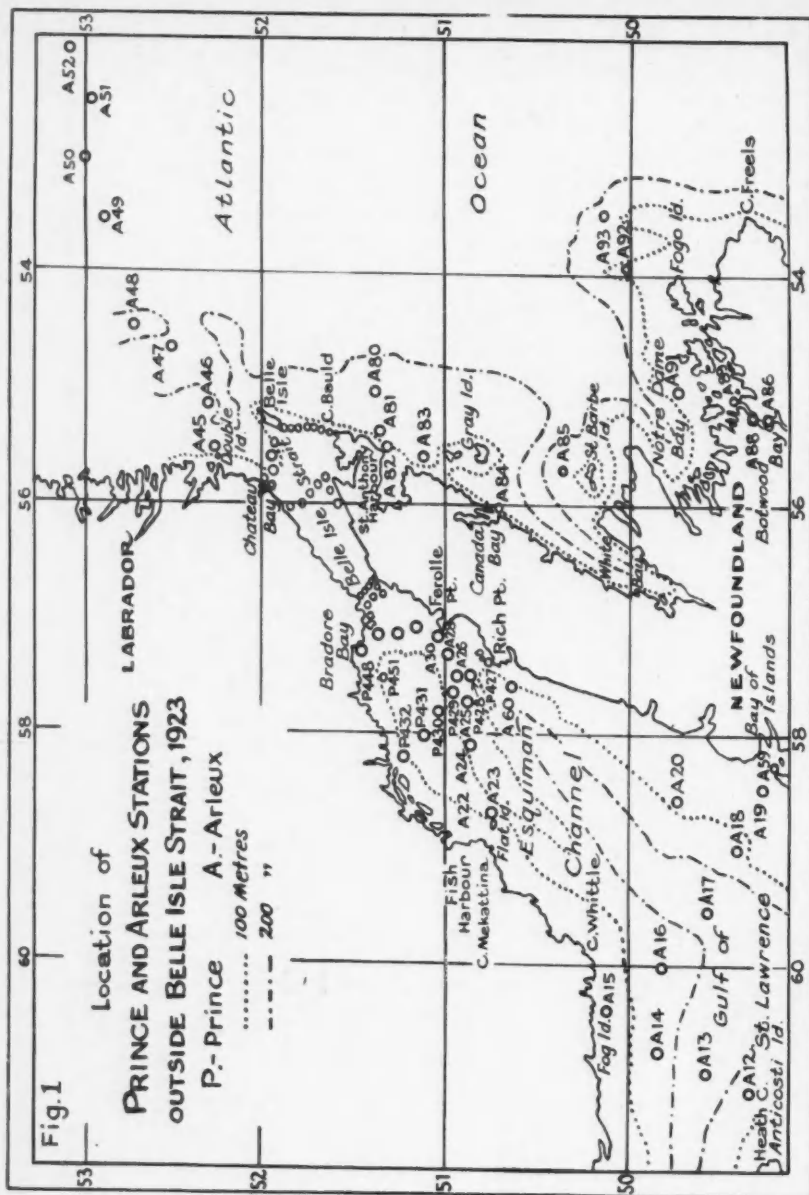
FIGURE 1. Belle Isle strait region showing "Prince" and "Arleux" stations *outside* the strait.
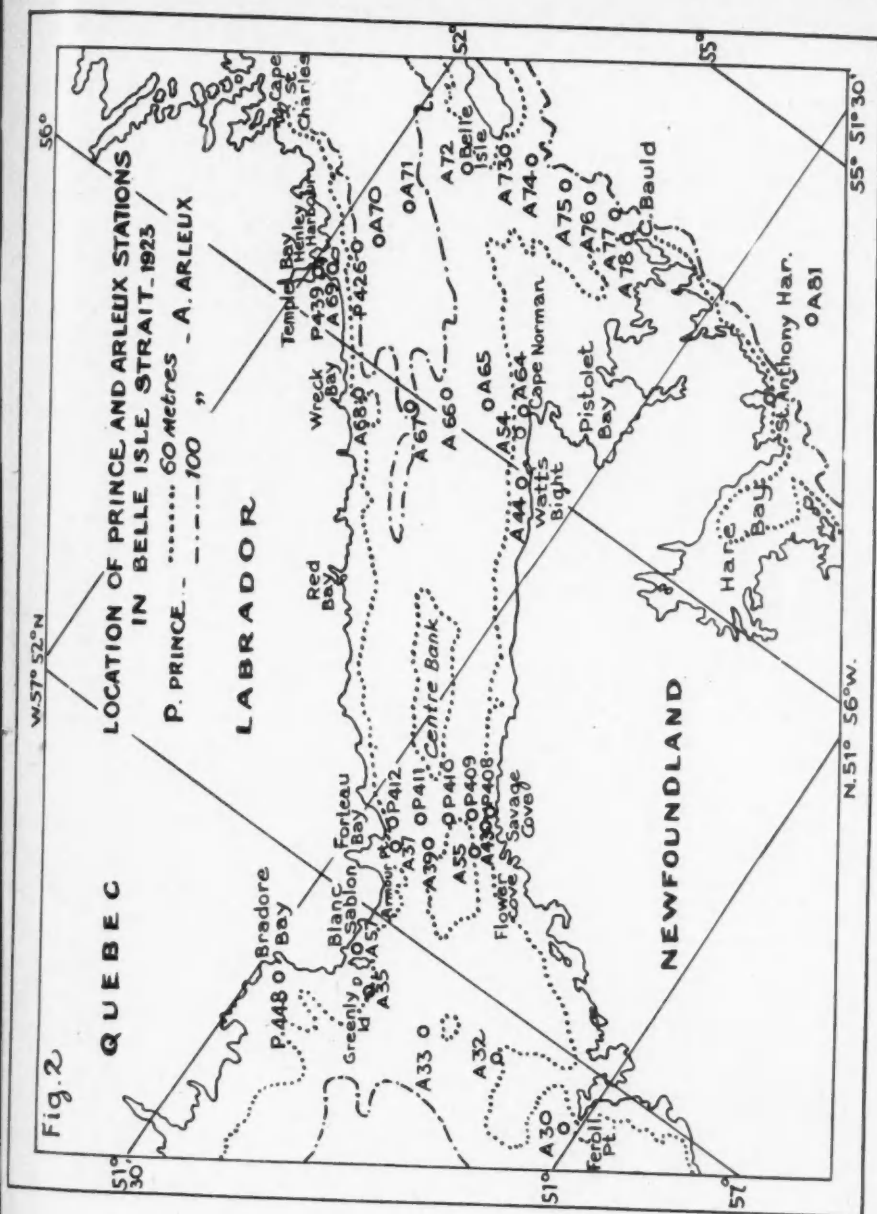
FIGURE 2. Belle Isle strait showing "Prince" and "Arleux" stations *inside* the strait.

"Prince" stations. Vertical hauls from the bottom to the surface and of varying durations of time, depending on depth, were made at a large number of stations also. A few oblique tows and vertical closing tows were taken at specified stations. The no. 5 material has been briefly treated by Pinhey (1926, 1927) and will be considered here also.

The stations for which no. 0 material has been examined are listed in table 1 and their locations are shown in figs. 1 and 2.

A list of tow results for each station is given in a manuscript report entitled "Distributional Records of Marine Amphipoda of Eastern Canada" (MS Report, Biological Stations, Fisheries Research Board of Canada, No. 404), and is available in libraries of stations of the Fisheries Research Board of Canada. The data given in the tables and figures of the present paper have been derived from these records. Outline charts and hydrographical sections have been prepared from British Admiralty charts of the Belle Isle strait region.

SYNOPSIS OF THE SPECIES

Hyperia galba (Montagu) G. O. Sars 1895

The species occurred infrequently in the Belle Isle strait region (fig. 3): Esquiman channel, "Arleux" 17, Aug. 12, 1 immature; Temple bay, "Prince" 439, Aug. 17, 10 immature; bay of Exploits, "Arleux" 86, Sept. 14, 1 adult ♀, and "Arleux" 88, 1 adult ♂. All were taken in vertical or 25 m. tows, but none at the surface.

Outside the area, the species was noted in fair numbers at "Arleux" 102 and 103, off Miquelon island, chiefly in 25 m. tows. Huntsman (unpublished MS on Amphipoda of the Canadian Fisheries Expedition, 1914-15) gives localities off the outer coast of Nova Scotia and in the gulf of St. Lawrence for *Hyperia* sp.

Bigelow (1926) mentions the scarcity of *Hyperia* in the gulf of Maine. The species occurred there in small numbers at widely scattered stations during July and August only. Whiteley (1948) records it in the macroplankton of Georges bank.

Distribution. Stephensen (1940) says: "Very widely distributed in the boreal and arctic seas, mainly north of c.50° N. lat.; probably circumpolar. . . . Possibly also found in the southern hemisphere".

Hyperia medusarum (O. Fr. Müller) G. O. Sars 1895

A single specimen was taken in the 25 m. tow at "Arleux" 37, off Amour point (fig. 3) on Aug. 17. Very young *Hyperia* from "Prince" 439 may have been incorrectly determined as *Hyperia galba* (see above) instead of *Hyperia medusarum.*

Outside the area, Rathbun (1909) records it in *Cyanea arctica* from Domino harbour, Labrador. Shoemaker (1926) gives localities for this species in Hudson bay. Bigelow (1926) reports it as being relatively scarce in the gulf of Maine, but in contrast to *H. galba* it occurred there in winter also.

Distribution.   Stephensen (1923, 1940) describes it as a boreo-arctic species, widely distributed in the northern Atlantic with adjacent arctic seas.

Hyperoche medusarum (Krøyer)
  Hyperoche krøyeri   G. O. Sars 1895

The species was taken at many of the stations outside the strait of Belle Isle, at 4 stations on the north side of the strait and at several stations along the north and west side of the Esquiman channel (fig. 3).   The maximum number per station was 9 specimens, all immature, and taken in the horizontal tow at "Arleux" 75 off Belle isle.   Its frequent occurrence close to shore and in bays may be related to the coastal distribution of large Scyphomedusae (*Cyanea*, *Aurelia*). *Hyperoche*, like *Hyperia*, is known to inhabit the stomach cavities of large jellyfish.

Hyperoche medusarum is evidently much more abundant, although not necessarily more widely distributed, on the eastern Canadian coast than are the two species of *Hyperia*.   Whiteaves (1901) took it between Anticosti island and the Gaspé peninsula.   Huntsman (unpublished MS) records it between Anticosti island and Fog island, Quebec, in Cabot strait, at several localities off the outer coast of Nova Scotia and south of Newfoundland.   Shoemaker (1930) records it from the Cheticamp expedition of 1917 in the gulf of St. Lawrence.   Bigelow (1926) gives summer and winter records from the gulf of Maine, where it was rather more numerous than *Hyperia* and as a rule found close to shore.

Distribution.   Various authors list it as a boreoarctic species widely distributed in the North Atlantic with adjacent Arctic seas.   It is generally found near the surface and very rarely beyond the 1000 m. line.   It is probably circumpolar.

Themisto abyssorum (Boeck)
  syn: *Parathemisto oblivia* (Krøyer)   G. O. Sars 1895

The species was widely distributed in the Belle Isle strait region (fig. 4); it was the dominant amphipod in the relatively warm south and east waters of the Esquiman channel and in the confines of Botwood bay on the east coast of Newfoundland.   In the strait proper, it occurred at only 12 of 38 stations.   The relatively small numbers taken, particularly at south shore stations, may be related to the shallowness of the water.   A few specimens have been taken at some of the Labrador current stations but never in surface tows.   The work of Whiteaves (1901), Huntsman (unpublished MS), Pinhey (1926 and 1927) and Shoemaker (1930) shows *Themisto abyssorum* to be widely distributed in and around the gulf of St. Lawrence.   Bigelow (1926) gives a few late-summer records from open water areas in the gulf of Maine.

Distribution.   The species is mainly arctic but also occurs in the North Atlantic and Davis strait.

Fig. 3

DISTRIBUTION OF HYPERIA, HYPEROCHE
IN THE BELLE ISLE STRAIT REGION-1923
● HYPEROCHE MEDUSARUM ■ HYPERIA GALBA
▲ HYPERIA MEDUSARUM
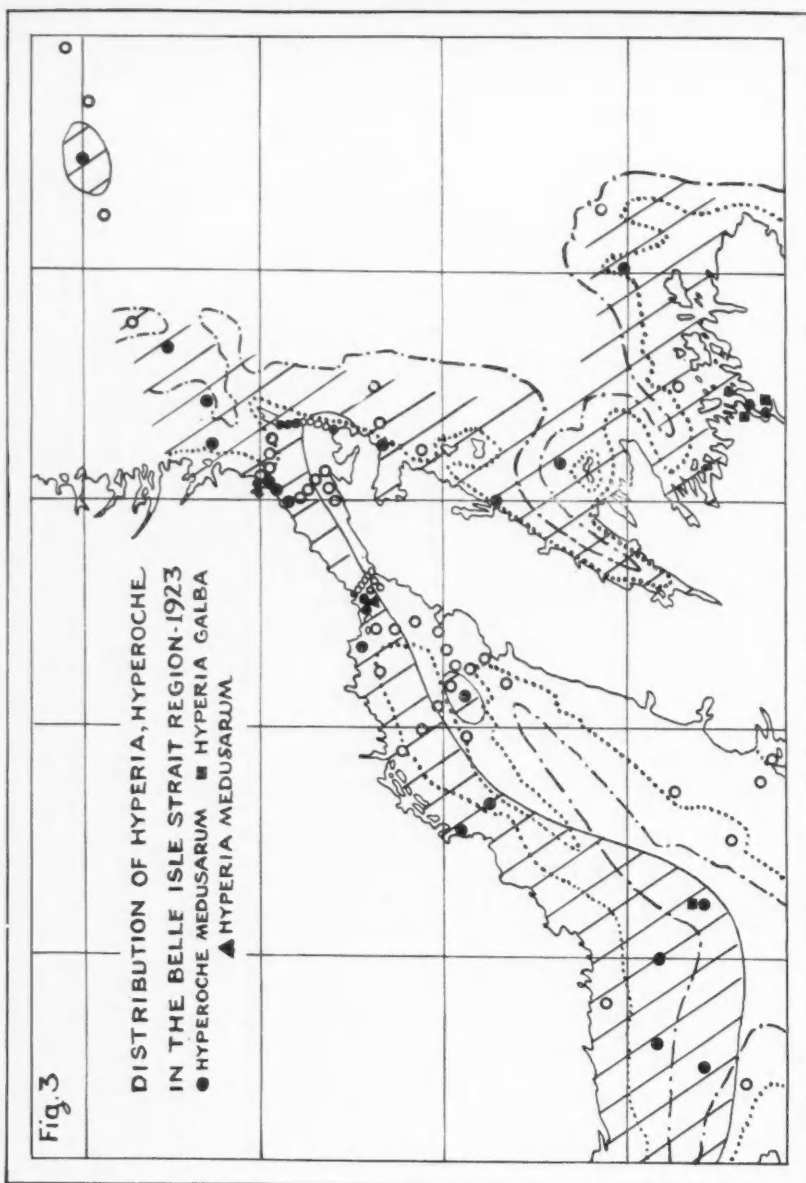
FIGURE 3. Distribution of *Hyperoche* and *Hyperia* sp. in the Belle Isle strait region.

Fig. 4

DISTRIBUTION OF THEMISTO ABYSSORUM
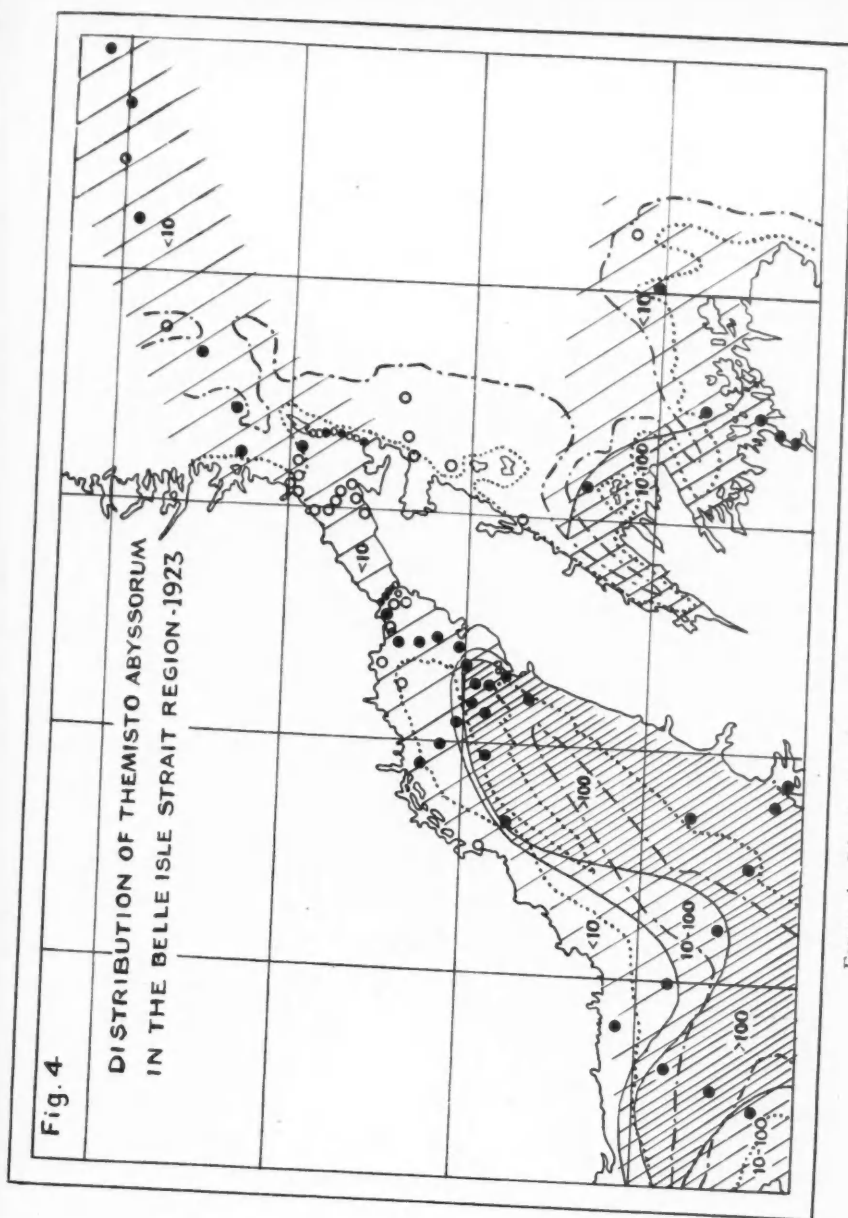IN THE BELLE ISLE STRAIT REGION·1923

FIGURE 4. Distribution of *Themisto abyssorum* in the Belle Isle strait region.

Themisto compressa form *compressa*   Goës
   Syn: *Euthemisto compressa*   G. O. Sars 1895
       Euthemisto gaudichaudi (partim)   Barnard 1932

Themisto compressa (young included) occurred everywhere in the Belle Isle strait region (fig. 5) with the exception of "Arleux" stations 22, 55 and 88.   It was the dominant pelagic amphipod in the strait proper, along the north and west side of the Esquiman channel and at coastal stations in the Labrador current proper.   More than one-third of all stations showed frequencies of 100 or greater in no. 0 tows.

Huntsman (unpublished MS) and Shoemaker (1930) give numerous records for the gulf of St. Lawrence and from the outer coast of Nova Scotia.   Pinhey (1926, 1927) using no. 5 material found *T. compressa* form *compressa* widespread in the Belle Isle strait region.   Contrary to her findings, form *compressa* is more numerous and more extensive in distribution in the area than form *bispinosa*. Bigelow (1926) shows form *compressa* to be a permanent and characteristic inhabitant of all parts of the gulf of Maine except the immediate coastal zone. Whiteley (1948) found it numerous over the Georges bank in summer and early autumn but scarce in early spring.

Distribution.   It is found in the North Atlantic and Davis strait but is rare in arctic waters.   Stephensen (1940) gives the distribution as western Greenland, Iceland, and so on, to the Antarctic (see Barnard, 1932; Stebbing, 1888).

Remarks.   Form *compressa* exhibits considerable variation in morphological structure in relation to size.   The young lack the dorsal carination and pronounced development of segments 5 and 6 of peraeopod 3.   Both features are given by Sars as adult characteristics.   For immature female stages up to 9 mm. in body length, the ratio of the lengths of antenna 1 to antenna 2 was found to be constant and equal approximately to $^3/_4$.   Sexual differentiation of the antennae occurred in some males of 5 mm.   Fully developed antennae were present in males of 12 to 15 mm., the maximum body length observed.

Themisto compressa form *bispinosa* (Boeck)
   syn: *Euthemisto bispinosa*   G. O. Sars 1895
       Euthemisto gaudichaudi (partim)   Barnard 1932

Form *bispinosa* was generally distributed in the Belle Isle strait region (fig. 6). It was less numerous than form *compressa* except at "Arleux" 50, 51 and 93. These stations were well out in the Labrador current proper, and more than 100 specimens of form *bispinosa* were taken at each.   In a sample of 400 taken from an estimated 150,000 specimens in the no. 0 surface material at "Arleux" 93, form *bispinosa* outnumbered form *compressa* 8 to 7, a ratio which Pinhey (1927) found to be 3 to 1 in no. 5 surface material.

Records of Stebbing (1888), Vosseler (1901), Huntsman (unpublished MS), Pinhey (1926, 1927) and Shoemaker (1930) show form *bispinosa* to be widely

Fig. 5

DISTRIBUTION OF
THEMISTO COMPRESSA f. COMPRESSA
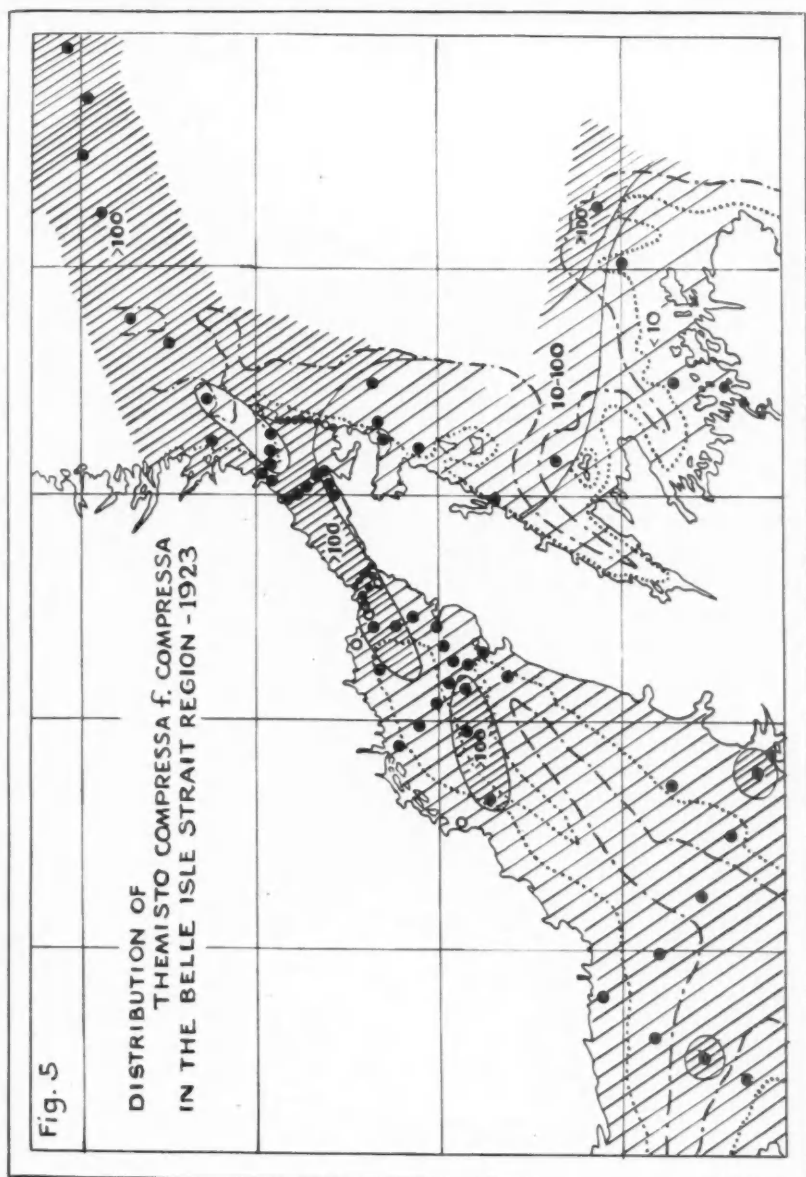IN THE BELLE ISLE STRAIT REGION -1923

FIGURE 5. Distribution of *Themisto compressa* form *compressa* in the Belle Isle strait region.

distributed in offshore waters of Newfoundland and Nova Scotia, but less frequently encountered in the gulf of St. Lawrence. Bigelow (1926) gives numerous records from the gulf of Maine. He finds form *bispinosa* is more oceanic and exhibits more definite seasonal movement toward and away from the coast than *compressa* does. He notes a preponderance of form *bispinosa* over form *compressa* in the deep offshore hauls.

In agreement with the oceanic existence of form *bispinosa* is its distribution in the Belle Isle strait region (fig. 6). Its absence from the north and west sectors of the Esquiman channel is clearly related to its sporadic occurrence at coastal water stations in the outer Atlantic, as very few (if any) are carried into the gulf via the Belle Isle strait branch of the Labrador current. Those specimens of form *bispinosa* taken in the south and east parts of the gulf may exist all year round in the deep cold water there, or rather more likely have entered the region via the deep inflowing waters of Cabot strait to the south.

Distribution. The distribution of form *bispinosa* is in the main as in the form *compressa* (see above). Both forms are as a rule taken together but only exceptionally in northern (arctic) waters. Barnard (1932) finds *bispinosa* more abundant in the open ocean of the southern hemisphere, but less eurythermal than *compressa*.

Remarks. Using descriptions and figures given by Sars (1895) and Stephensen (1923), the *bispinosa* young of less than 5 mm. in body length are not ordinarily distinguishable from *compressa* young. Specific determination of both forms of *Themisto compressa* is confined to specimens greater than 5 mm. (approx.); those which are smaller are classed as *Themisto* young. The distribution of *Themisto* young is given in fig. 7.

Many specimens 5-8 mm. long could not be determined precisely as to form, since certain characteristics distinguishing the form *bispinosa* were imperfectly developed. Indeed, Huntsman (unpublished MS) notes an 11 mm. specimen for which the third peraeopod of the left side was that of form *compressa* whereas that of the right side fitted the description of form *bispinosa*. Interbreeding of the two forms may occur. Failing other interpretation, these "intermediate" forms are treated as immature stages of form *bispinosa* (fig. 6).

Themisto libellula (Mandt)
  syn: *Euthemisto libellula* G. O. Sars 1895

The species was taken in no. 0 net at 34 of the 83 stations (fig. 8), all of which were located in waters influenced to some degree by the Labrador current. At "Arleux" 35 off Greenly island a maximum number per station of 113 specimens was taken.

Whiteaves (1901) reports *E. libellula* from Bradelle bank in the gulf of St. Lawrence. Rathbun (1909) gives Labrador records. Shoemaker (1926) finds *T. libellula* in Hudson and James bay localities. Pinhey (1926) notes a single specimen from "Arleux" 35 in Belle Isle strait. Dunbar (1946) gives a

FIG. 6

DISTRIBUTION OF
THEMISTO COMPRESSA f. BISPINOSA
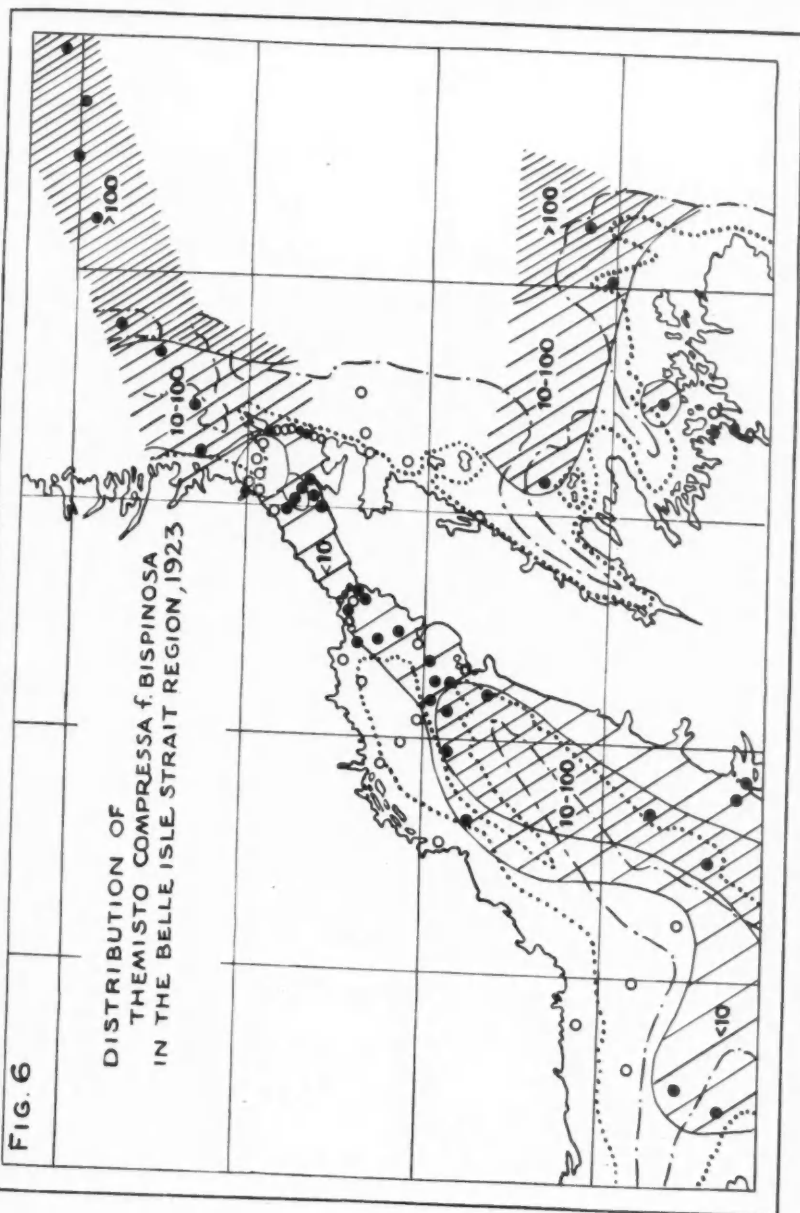IN THE BELLE ISLE STRAIT REGION, 1923

FIGURE 6. Distribution of *Themisto compressa* form *bispinosa* in the Belle Isle strait region.

FIG. 7

DISTRIBUTION OF
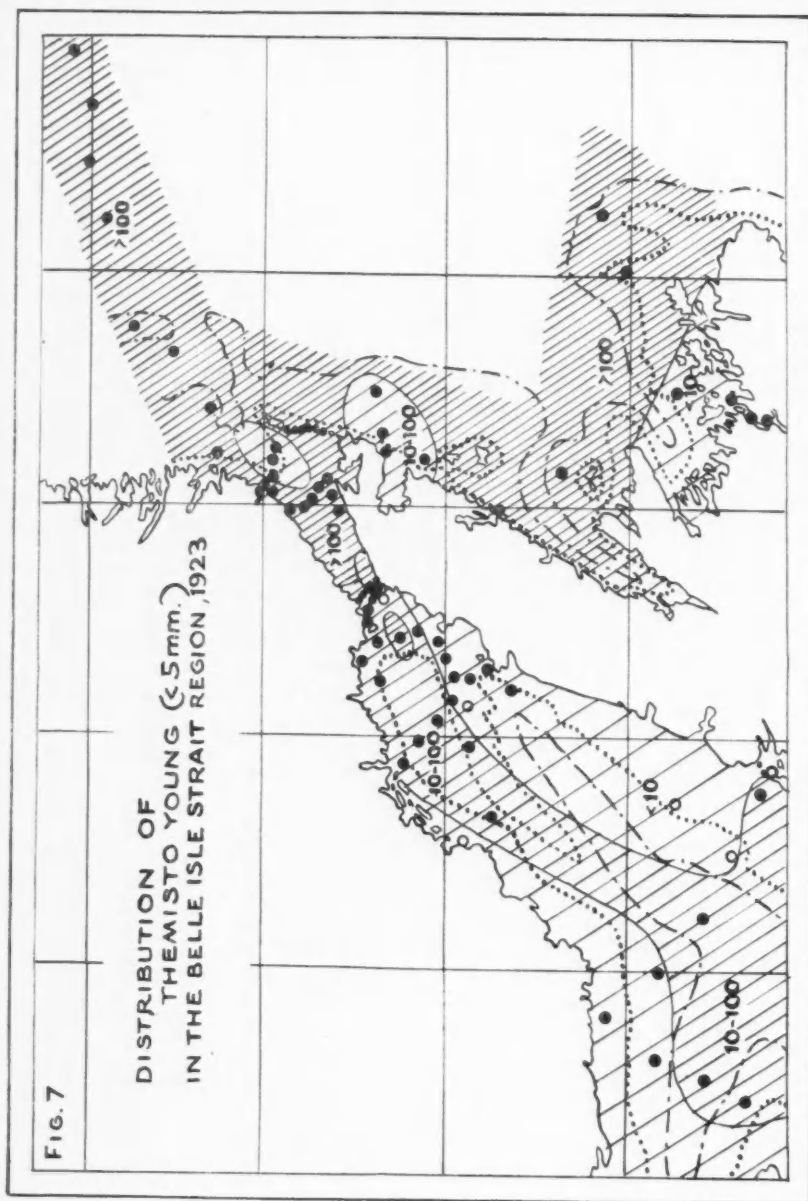THEMISTO YOUNG (<5mm.)
IN THE BELLE ISLE STRAIT REGION, 1923

FIGURE 7. Distribution of *Themisto* young in the Belle Isle strait region.

FIG. 8

DISTRIBUTION OF THEMISTO LIBELLULA
IN THE BELLE ISLE STRAIT REGION. 1923
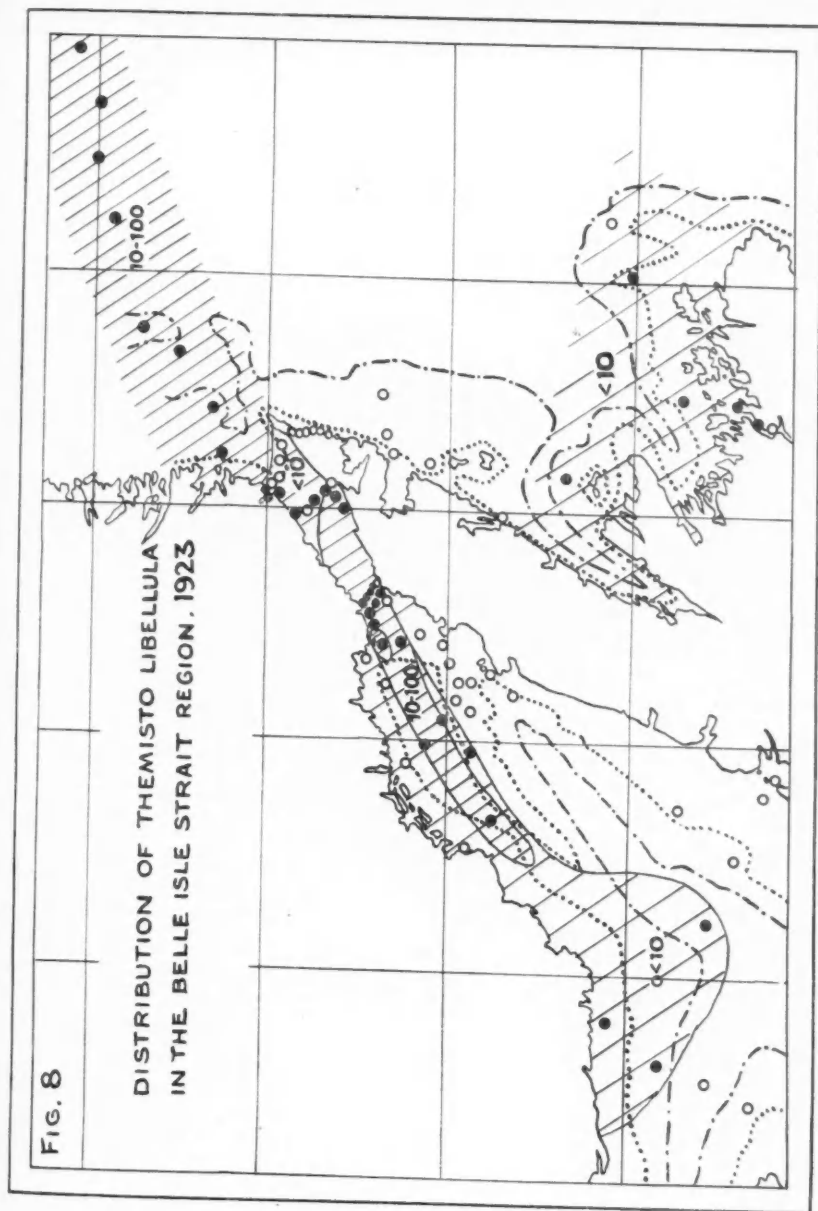
10-100

<10

<10

10-100

<10

<10

FIGURE 8. Distribution of *Themisto libellula* in the Belle Isle strait region.

description of *T. libellula* in Baffin island coastal waters. It is notable that Huntsman (unpublished MS) did not find this species in the gulf of St. Lawrence nor off the outer coast of Nova Scotia. Furthermore, Bigelow (1926) found no trace of *T. libellula* in the gulf of Maine over a three-year period.

Distribution. Stephensen (1940) says: "A widely distributed arctic species, pelagic, a form characteristic of arctic waters".

Phronima sp.

A single specimen 2 mm. in length was taken in the 25 m. tow at "Prince" 448 in Bradore bay on September 10 (fig. 1).

Huntsman (unpublished MS) and Bigelow (1926) give *Phronima* records from stations along the continental slope off the Nova Scotian and New England coasts. Rarely is this tropical oceanic genus found in shelf water. The northern Atlantic limit for common occurrence of *P. sedentaria* Forskal (and presumably also *P. atlantica*) is a little north of 40°N. (Stephensen, 1923). The Bradore bay occurrence is 51° 25′ and inside the gulf of St. Lawrence, a truly remarkable indication of tropical water in the Belle Isle strait region.

Pseudalibrotus glacialis G. O. Sars

Thirty-six specimens were taken at 15 stations, all located in waters influenced by the Labrador current (fig. 9).

No previous records of this species for the east coast of Canada have been found. Stephensen (1923) gives three localities from the southwest coast of Greenland. The present record constitutes a southward extension of range for this species to 49° 30′ N.

Distribution. It is an arctic, pelagic and probably circumpolar species.

Calliopius laeviusculus (Krøyer) (incl. C. rathkei Zaddach).

With the possible exception of "Prince" 439, *Calliopius* occurred at 28 stations influenced by waters of the gulf of St. Lawrence (fig. 10). It was found almost invariably in surface tows only, but there were 25 m. records at "Arleux" 67 and 75. It was most numerous in the "mixed" water at "Arleux" 33 and 66, where 22 and 24 specimens respectively were taken in surface tows.

Calliopius is a common, littoral form of the New England and Canadian Atlantic coasts. Rathbun (1909) records it from Henley harbour in Chateau bay. This is close to the present record at "Prince" 439. In the no. 5 material, Pinhey (1926) found it at "Arleux" 33 and 35, at the western entrance to Belle Isle strait.

Distribution. Stephensen (1940) describes it as "a mainly boreal, littoral species, found in the northernmost part of the Atlantic with adjacent arctic seas and eastern Asia".

149

FIG. 9

DISTRIBUTION OF
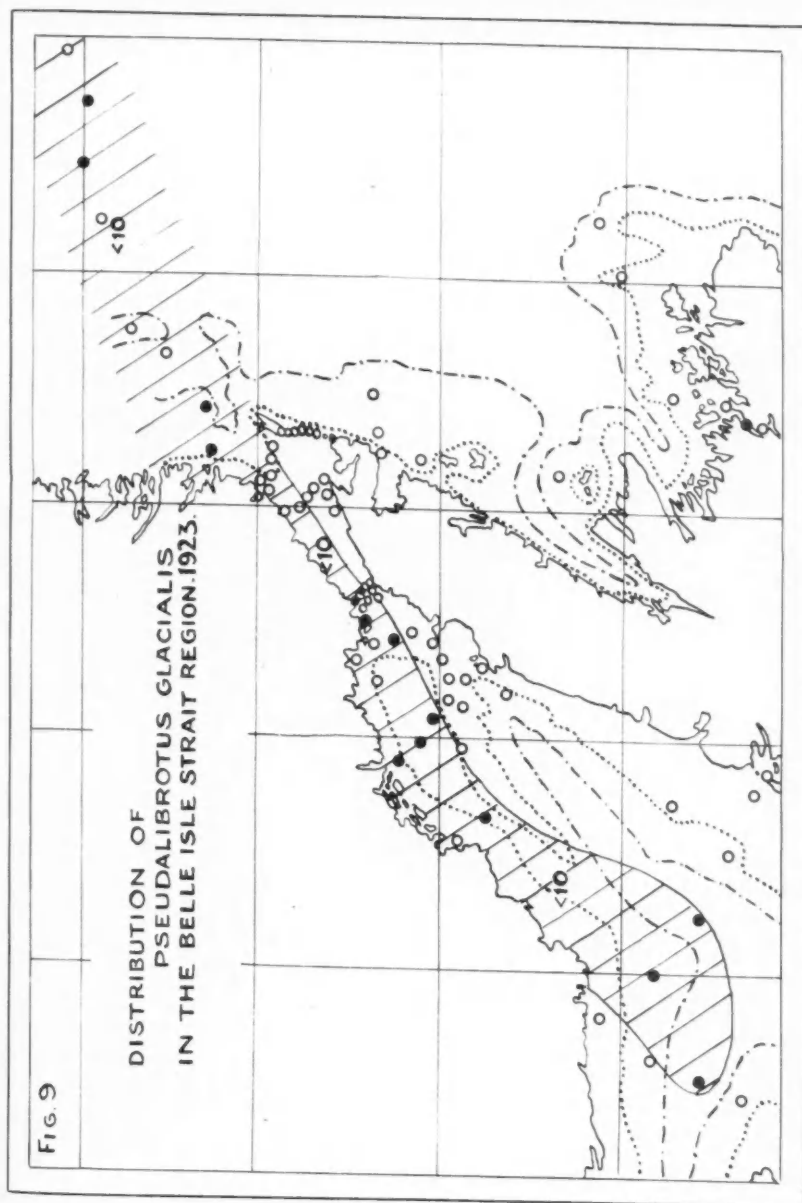PSEUDALIBROTUS GLACIALIS
IN THE BELLE ISLE STRAIT REGION. 1923.

FIGURE 9. Distribution of *Pseudalibrotus glacialis* in the Belle Isle strait region.

FIG. 10

DISTRIBUTION OF
CALLIOPIUS LAEVIUSCULUS
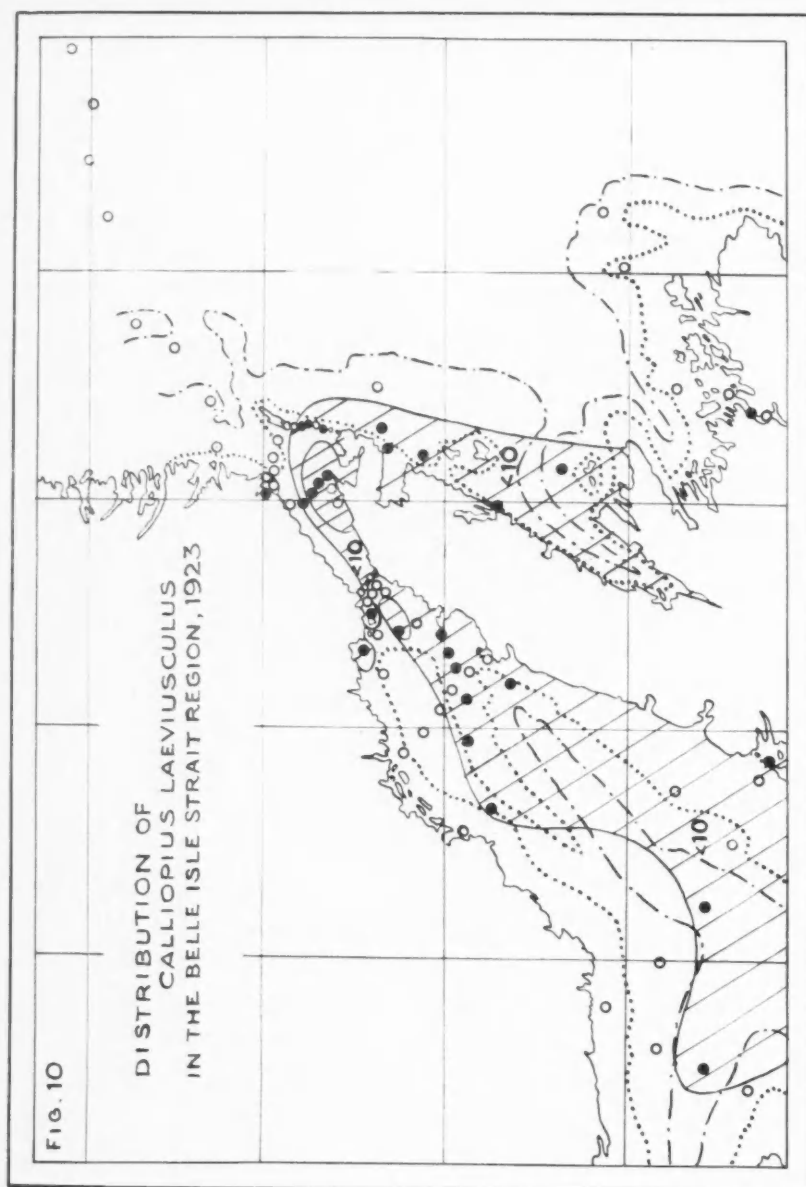IN THE BELLE ISLE STRAIT REGION, 1923

FIGURE 10.   Distribution of *Calliopius laeviusculus* in the Belle Isle strait region.

RELATION OF SPECIES TO OCEAN CURRENTS

Indicator Species

The maps of species distribution (figs. 3 to 10) for the previous section indicate that certain of the Amphipoda are indigenous to the cold Labrador current and others to the relatively warm gulf of St. Lawrence; the remainder are widely distributed in both bodies of water. Considerable mixing of the two streams occurs over a wide area. The zone of demarcation between stations with cold water fauna and those with warm water fauna is not sharp. Indeed, more than two-thirds of the stations were located in areas at the time influenced to some degree by both currents (that is, in mixed water). On the basis of hydrographical data (figs. 11 and 12) and geographical location (figs. 1 and 2), eight stations ("Arleux" 45 to 52 inclusive) all north and east of the strait can be selected as being in Labrador current water only. Nine stations ("Arleux" 18, 19, 20, 28, 30, 59 and 60 and "Prince" 427 and 428) all along the west coast of Newfoundland as far north as Ferolle point are situated in gulf water only.

TABLE II. Relative abundance of species at 8 cold, 66 mixed
and 9 warm water stations for all tows.

Amphipoda	Cold water stations		Mixed water stations		Warm water stations	
	Number specimens taken	Average number per station	Number specimens taken	Average number per station	Number specimens taken	Average number per station
H. medusarum	8	1.0	51	0.8	0	0
T. abyssorum	12	1.5	4140	62.8	2958	328.7
T. compressa	1569	196	268	4.1	38	4.2
T. bispinosa	1632	204	2889	43.9	204	2.3
Themisto young	3047	381	4100	62.0	60	6.7
T. libellula	197	24.5	317	4.8	0	0
P. glacialis	6	0.8	31	0.5	0	0
C. laeviusculus	0	0	108	1.6	9	1.0

Hyperoche medusarum, Themisto libellula and *Pseudalibrotus glacialis* are found in Labrador current water but not in gulf water. On this basis, the three species indicate the presence of Labrador current water wherever found in the Belle Isle strait region. *Calliopius laeviusculus* is found in gulf water but not in Labrador current water; it indicates warm gulf water in the area. *Themisto abyssorum* in large numbers signifies gulf water. Both forms of *Themisto compressa* and *Themisto* young are most numerous in the Labrador current, but are sufficiently numerous in gulf waters to mask any relation to ocean currents in the Belle Isle strait region.

Fig. 11

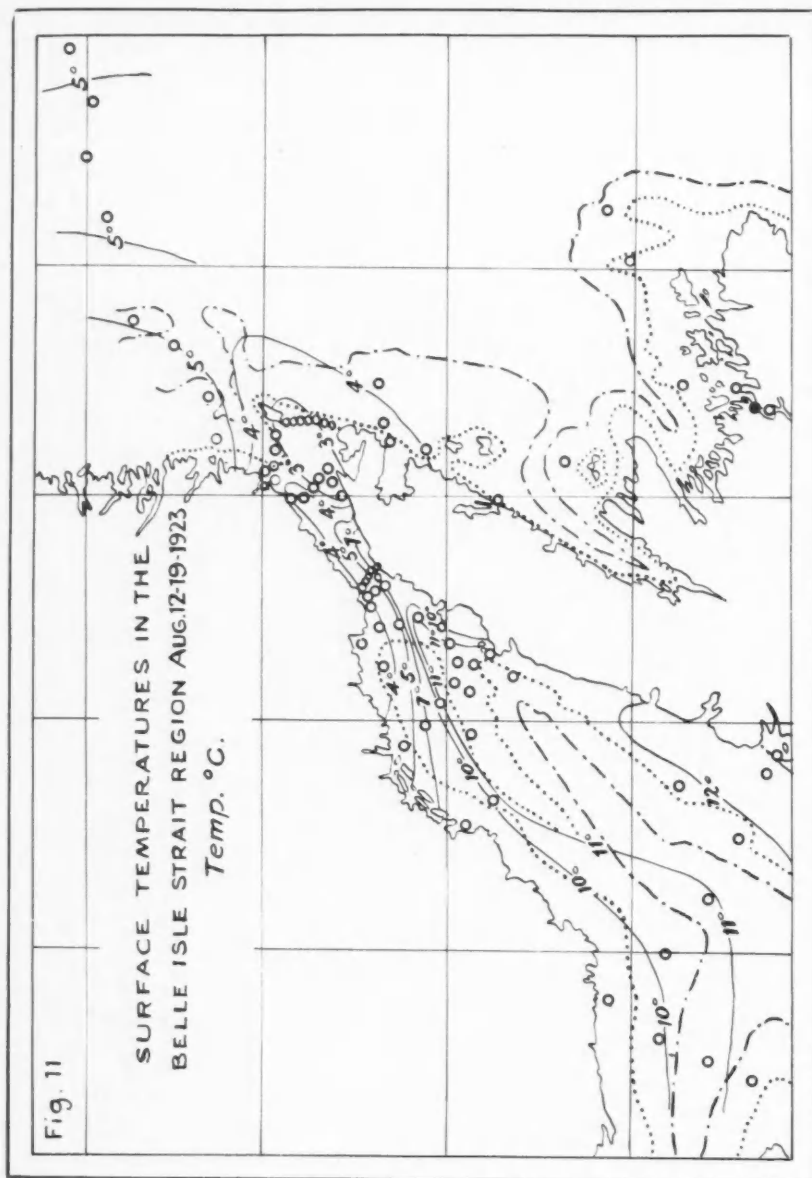SURFACE TEMPERATURES IN THE
BELLE ISLE STRAIT REGION AUG. 12-19-1923
Temp. °C.

FIGURE 11. Surface temperatures in the Belle Isle strait region, Aug. 12 to 21, 1923.

SURFACE SALINITIES IN THE
BELLE ISLE STRAIT REGION, AUG.12-19,1923
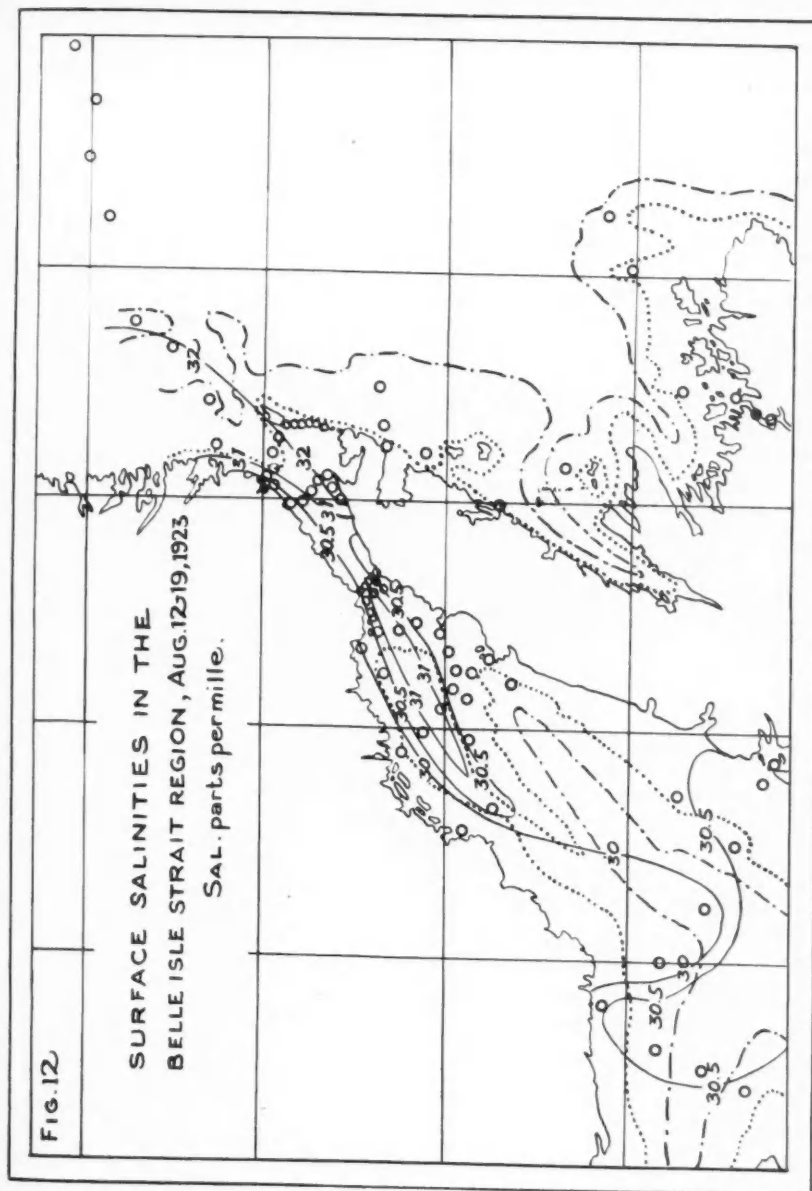SAL. parts per mille.

Fig.12

FIGURE 12. Surface salinity in the Belle Isle strait region, Aug. 12 to 21, 1933.

Hyperia galba and *H. medusarum* were seldom encountered (fig. 3) in the area, but their distribution and habits point to an association with the cold Labrador current and absence from the warmer waters of the gulf. The *Phronima* sp. indicates an extension of tropical water into the gulf.

DETAILED RELATION TO CURRENTS

Along with hydrographical data, the results of the previous section can be used in remarkable fashion to determine the movements of water from the Labrador current and from the gulf through the region. In the strait proper, the complex water movements outlined by Huntsman (1925) are corroborated by the evidence of these indicator species. Pinhey (1926) has illustrated this situation with other indicator species, notably of the marine Copepoda. A hydrographical section was made at the end of July across the Esquiman channel, where the oblique Mekattina bank separates it into two deep channels, one along each shore. "Prince" 427, 428 and 429 are on the Newfoundland side of the crest of the bank and have warm (over 10°C.) gulf water at the surface, which is lacking at "Prince" 430, 431, and 432 on the Quebec side. *Themisto abyssorum* was in large numbers at the three "warm" stations (table III). *T. libellula* and *P. glacialis* were absent from the "warm" stations but present at the three others. The mixing of cold Labrador current water with the extensive layer of warm gulf water was thus limited to the north and west sections of the Esquiman channel.

TABLE III. Frequency of occurrence of Amphipoda, Barbace point to Mistanoque island, July 30-31, 1923, for all tows.

Amphipoda	"Cold" Stations			"Warm" Stations		
	"Prince" 432	431	430	429	428	427
T. abyssorum	9	1	14	444	47	151
T. libellula	0	2	4	0	0	0
P. glacialis	2	1	2	0	0	0

TABLE IV. Frequency of occurrence of Amphipoda, Sandy cove to Amour point, Aug. 7 (left) and Sept. 7 (right), 1923, for all tows.

Amphipoda	"Prince" Stations				
	412	411	410	409	408
T. abyssorum	4:0	1:0	1:0	1:0	0:0
T. libellula	3:0	1:0	26:0	0:0	0:0
P. glacialis	8:0	1:0	0:0	0:0	0:0
C. laeviusculus	0:0	0:0	0:1	0:0	0:1

A similar section was made across the western part of Belle Isle strait in early August. "Prince" 408, 409, and 410 are on the south (Newfoundland) side, and have relatively warm (8° to 9°C.) water at the surface. Icebergs were reported as scattered all across the strait at this time, but mostly on the north side. They were evidence that there had been strong movement from the Labrador current.

P. glacialis was taken only at "Prince" 411 and 412 on the Labrador side, with cold (5° to 6°C.) water at the surface (table IV). *T. libellula* occurred there in small numbers but was most numerous in mid-channel at "Prince" station 410. *T. abyssorum* was taken in small numbers all across the strait, except in shallow water at "Prince" station 408. This distribution indicates that warm south-shore water had been drawn into the westward circulation of cold Labrador current water, resulting in mixed water all across the strait at that time.

In the section made on September 7, and which corresponds exactly to the section previously discussed, the surface water all across the strait was 11° to 12°C. On the south side, the warm water extended to 40 to 50 m. depth. The single specimens (table IV) of *Calliopius* at "Prince" 408 and 410, and the absence of arctic forms (notably *T. libellula*) from all five stations indicate that warm gulf water extended over the cold underlying water virtually unmixed to the north shore.

TABLE V. Frequency of occurrence of Amphipoda; cape Norman to Wreck bay, Sept. 6, 1923, for all tows.

Amphipoda	"Arleux" Stations				
	68	67	66	65	64
T. abyssorum	0	1	0	0	0
T. libellula	1	0	1	2	0
H. medusarum	1	0	0	0	0
C. laeviusculus	0	3	24	3	18

A section was made on September 6 across the eastern part of the strait. Gulf water as warm as 10°C. at the surface had by that time reached cape Norman on the south side. Eighteen specimens of *C. laeviusculus* were taken at "Arleux" 64 on the south side (table V). "Arleux" 65, 66, and 67 were in "mixed" water with temperature of 8°, 7° and 5°C. at the surface respectively. *C. laeviusculus* was present at all three, but was absent from "Arleux" 68 on the north side (surface temperature about 9°C.) where single specimens of *T. libellula* and *H. medusarum* were taken. *T. libellula* was also taken in the "mixed" water at "Arleux" 65 and 66. This section illustrates best the warm, comparatively fresh gulf water of the south side tending to overlie the cold, more salt Labrador current of the north side.

In early September, a section was made across the eastern entrance to the strait from Belle isle to cape Bauld (fig. 2). "Arleux" 73 and 74 are immediately south of Belle isle and have cold (5°C.) water at the surface. They show the presence of *H. medusarum* (table VI). "Arleux" 75 and 76 are in mixed water of 6°C. at the surface and show *H. medusarum*, *T. abyssorum*, and *C. laeviusculus*. "Arleux" 77 and 78 are on the south side, have warm (over 9°C.) gulf water at the surface, and show only *T. abyssorum* and *C. laeviusculus*.

TABLE VI. Frequency of occurrence of Amphipoda, Belle isle to cape Bauld, Sept. 7, for all tows.

Amphipoda	"Arleux" Stations					
	73	74	75	76	77	78
C. laeviusculus	0	0	1	1	0	1
T. abyssorum	0	0	1	0	1	0
H. medusarum	1	2	9	0	0	0

Evidently the gulf water was passing around cape Bauld only within a narrow range close to the Newfoundland coast, but its influence was shown to a slight extent across to Belle isle.

Figs. 13 and 14 give surface temperatures in Belle Isle strait during the middle of August and early September respectively.

In August, warm gulf water was present along the south side of the strait to a point somewhat east of Savage cove. A body of very cold surface water occupied the eastern part of the strait and extended westward along the north side into the Esquiman channel. The arctic species *T. libellula* and *P. glacialis* were taken there. In September warm gulf water was present all across the western part of the strait, but was limited to the south side in the eastern part. No arctic species were taken except at the cold water stations in the north and eastern part of the strait.

The salient features of the horizontal distribution can be summed up as follows. Arctic forms such as *T. libellula* and *P. glacialis* extend into the gulf beyond the limits set by reproductive stenothermy. This distribution is sterile owing to the heating of the Labrador current as it becomes dissipated southward in the Esquiman channel (fig. 11), a situation which eventually proves lethal to surface-swimming forms. *Themisto abyssorum*, on the other hand, is an essentially arctic form which, as its specific name implies, is normally encountered in deep water. In the deep water of the gulf and in Botwood bay, a permanent layer of very cold water exists throughout the year. This evidently enables the species to breed successfully, as evidenced by the great numbers of young and immature stages taken within 30 m. of the surface (see MS Report, Biological Stations, Fisheries Research Board of Canada, No. 404 entitled "Distributional Records

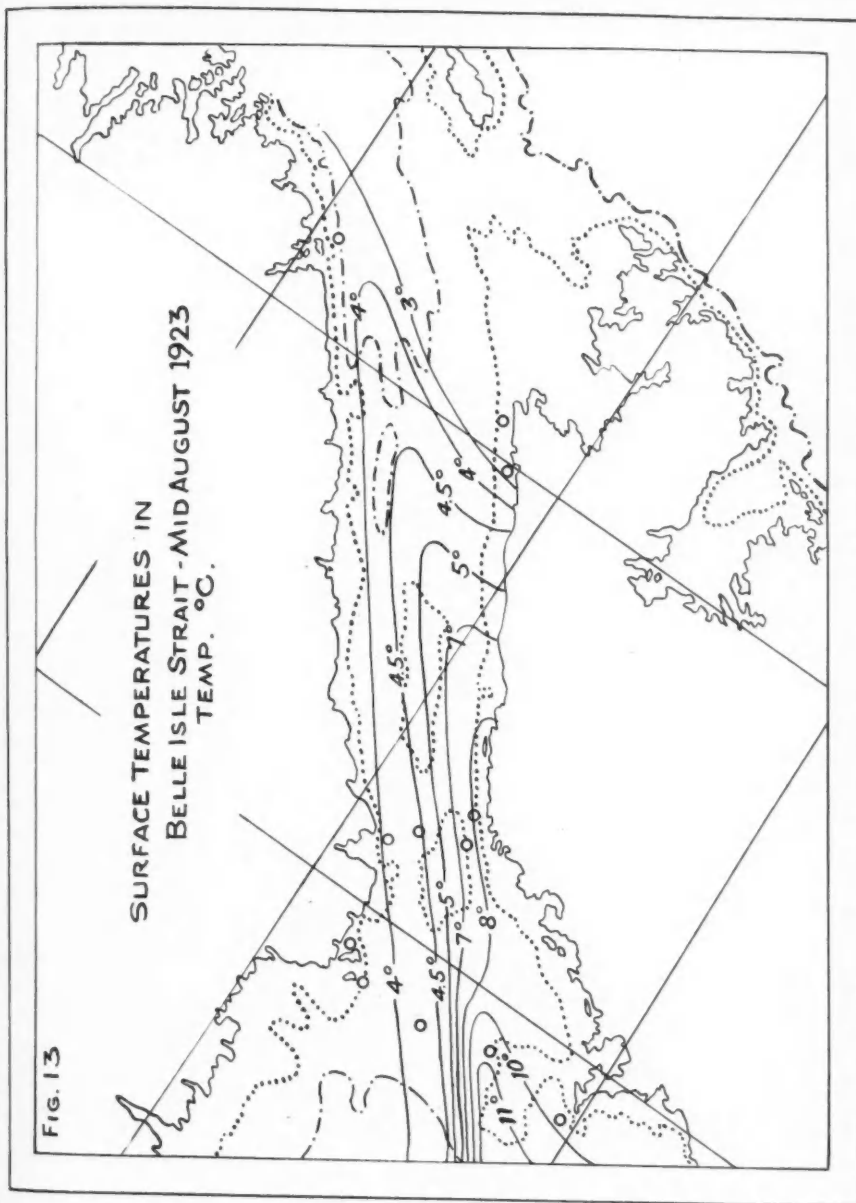SURFACE TEMPERATURES IN
BELLE ISLE STRAIT - MID AUGUST 1923
TEMP. °C.

FIG. 13

FIGURE 13. Surface temperatures in Belle Isle strait in mid-August, 1923.

Fig. 14

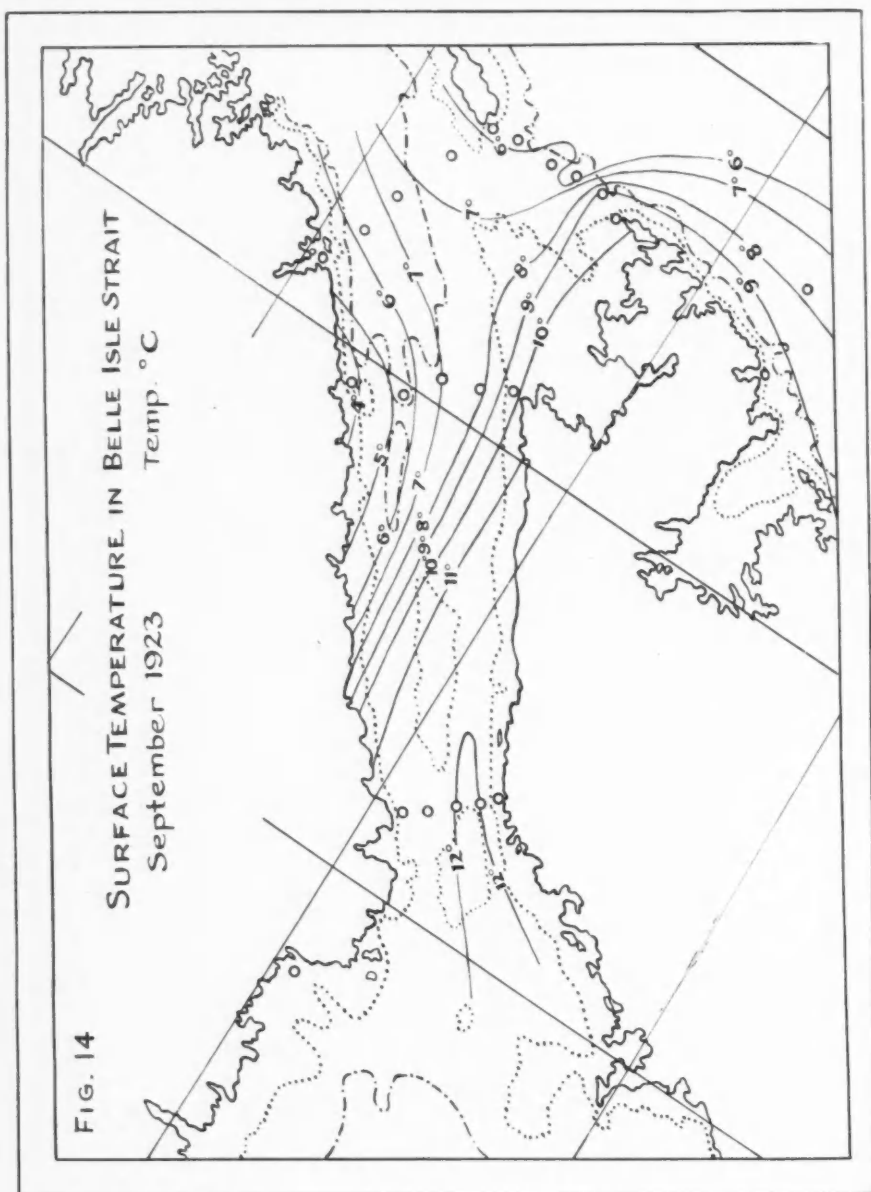Surface Temperature in Belle Isle Strait
September 1923
Temp. °C

Figure 14. Surface temperature in Belle Isle strait in early September, 1923.

of Marine Amphipoda of Eastern Canada", available on application to Fisheries Research Board).   Huntsman and Reid (1921) show that *Parathemisto* (*T. abyssorum*) is moderately successful in reproducing in the bay of Fundy, where deep water is similarly very cold.   The shallowness of the strait of Belle Isle may account for the few records of this species in the warm gulf water passing seawards along the south side of the strait.

VERTICAL DISTRIBUTION

The factors which may have a bearing on the vertical distribution of pelagic Amphipoda are many.   Certain of these factors can be discussed in some detail, based on available records from plankton tows.   Others such as food and predation can only be assumed to affect vertical distribution.   *Themisto* is known to feed upon copepods and other planktonic forms, even to the extent of being cannibalistic (Bigelow, 1926).   The very young stages may be dependent upon phytoplankton, which is most abundant near the surface.   Undoubtedly then, the vertical distribution is correlated with the availability of food of suitable

TABLE VII.   Relation of vertical distribution to light intensity.

Amphipoda	I Number of each species	II Number of stations	III Ratio: Stations with more at the surface Total number of stations					
			Night stations fraction	%	Day stations fraction	%	All stations fraction	%
T abyssorum	5244	28	$\frac{4}{10}$	40	$\frac{0}{18}$	0	$\frac{4}{28}$	14
*T. compressa**	3753	56	$\frac{7}{15}$	47	$\frac{23}{41}$	56	$\frac{30}{56}$	54
*T. bispinosa**	979	27	$\frac{0}{8}$	0	$\frac{11}{19}$	58	$\frac{11}{27}$	41
Themisto young	6250	50	$\frac{6}{14}$	43	$\frac{20}{36}$	56	$\frac{26}{50}$	52
T.libellula	394	20	$\frac{2}{6}$	33	$\frac{11}{14}$	79	$\frac{13}{20}$	65

*Figures compiled exclusive of "Arleux" 93.

size. Mackerel and herring, the two principal plankton-feeding vertebrates common in the gulf, take a heavy toll of *Themisto*. Adult *T. libellula* are the food of seals in the arctic (Dunbar, 1946). Predation by these enemies is conceivably less frequent in deeper water and the adults can quickly descend to the comparative safety of that region.

The relative abundance of hyperiid species at the surface and at 25 m. depth can be interpreted as resulting from light intensity. Although the method of population sampling employed on this expedition was not designed for a statistical analysis of plankton-tow results, the data presented in table VII indicate that the organisms differ widely in their response to daylight and darkness.

The number taken and the number of stations at which both surface and 25 m. tows were made, and in which the species occurred in either one or both tows, are given in columns I and II respectively. In column III the frequency with which each species was more numerous in surface tows than in 25 m. hauls is expressed as a fraction and as a percentage of all day or night stations at which the species was taken. Night stations are those for which tows were taken between 6.00 p.m. and 5.59 a.m. Day station tows were taken from 6.00 a.m. to 5.59 p.m.

Table VII shows that *Themisto abyssorum* was significantly more numerous at the surface by night than by day. This species tends to exhibit the negative phototropism which characterizes zooplankton in general and which Holmes (1901) found typical of many of the gammarid amphipods. *Themisto libellula* on the other hand, was more numerous at the surface by day. Dunbar (1946) finds *T. libellula* to be positively phototropic and concludes that this species has a higher centre of vertical distribution in the daytime than the bulk of the zooplankton. The preceding observations tend to confirm that fact.

Themisto bispinosa was more numerous in surface tows taken by day, the relationship being even more pronounced than that of *T. libellula*. *Themisto compressa* and *Themisto* young (*bispinosa* and *compressa* mixed) were also more numerous at the surface by day than by night. The probability that these last variations are significant is not high. On the whole, *T. compressa* and *Themisto* young were like *T. bispinosa* and *T. libellula* in being more numerous at the surface by day, whereas *T. abyssorum* was more numerous at the surface by night.

The very large amphipod plankton consisting of *T. compressa* and *T. bispinosa* taken at the surface at "Arleux" 93 in the Labrador current is attributed to rapidly changing light intensity in the sea just prior to complete darkness. This would apply also to the large amphipod plankton which Pinhey (1926) encountered in the no. 5 surface material at "Arleux" 48, but for which no. 0 material was not available. Both surface tows were taken at dusk; "Arleux" 93 at 7.45 p.m. on Sept. 14, and "Arleux" 48 at 8.50 p.m. on Aug. 18. Deep water individuals respond to rapidly decreasing light intensity in the early evening by swimming vertically in an attempt to remain in conditions of optimum light intensity. Unable to migrate further, they congregate for a short period in the diminishing light at the surface. The advent of complete darkness removes the

stimulus to light and the population scatters again to all levels during the night. Huntsman (1948) has discussed this phenomenon in relation to the breeding cycle of the polychaete *Odontosyllis enopla* in Bermuda waters. In view of work on this genus by Bigelow (1926) however it is unlikely that swarming of *Themisto* is a cyclic function of reproduction.

SIZE DISTRIBUTION

For many hyperiid species, the young and immature stages were very much more abundant than the adults of the same species. This feature was particularly true of all species of *Themisto*, whereas the adult stages of *Hyperia*, *Hyperoche* and *Calliopius* formed an appreciable part of the population.

In *T. compressa*, it was found (page 142) that sexual dimorphism is not fully developed until the organism is at least 10 mm. and usually 12 to 15 mm. in body length. This feature was more difficult to distinguish in *T. bispinosa*, as the few males of this form noted were about 13 mm. in length and with antennae but little differentiated from those of the female. For both forms of *T. compressa*, females with brood pouches were observed to be at least 12 mm. in length. The development of dorsal carination accompanies sexual maturation. In *T. abyssorum*, adult appearance was attained by individuals of 12 to 15 mm. in body length.

In *T. libellula*, on the other hand, not a single sexually mature specimen was obtained, although the largest measured approximately 25 mm. in body length. On the basis of antennal development, sex recognition in *T. libellula* is evidently not possible until the animal becomes quite large. In an adolescent male of 30.5 mm. Dunbar (1946) found the antennae to be less than one-quarter of the length of those of the mature male, but greater than those of the female of the same size. The absence of adult *T. libellula* from Belle Isle strait material may be attributed to the ability of large individuals to avoid the towing net, a point not definitely established. If adult stages were at all numerous, however, a few captures would be expected, since Dunbar (1946) took some adults in a stramin one-metre ring trawl in the known breeding locality of Lake harbour, Baffin island. Thus further evidence is necessary to establish the southern limit of distribution of adult *T. libellula*.

Examination of no. 0 material shows the adult stages of the *Themisto* species to be generally more numerous than the young at some distance from the sea coast and to be relatively more abundant (during darkness at least) in the 25 m. and deep vertical hauls. Bigelow (1926) observes that summer is the chief breeding season for this genus in the gulf of Maine; the larvae (young) are present at the surface whereas the adults frequent much deeper water. In the Belle Isle strait region this feature is particularly well illustrated by *T. abyssorum*. Undoubtedly then, the relatively high proportion of juveniles and young generally present at the surface, indicates that breeding takes place in the area in late summer.

SUMMARY

Analysis of the distribution of the pelagic Amphipoda in conjunction with hydrographical data has led to the following conclusions.

The distribution of certain of the Hyperiidae is correlated with the two principal water movements in the Belle Isle strait region, namely, the cold Labrador current which flows into the gulf along the north side of Belle Isle strait, and the warm water of the gulf of St. Lawrence which flows out to the Atlantic ocean along the south side of the strait. *Hyperoche medusarum* (Krøyer), *Themisto libellula* (Mandt) and *Pseudalibrotus glacialis* Sars are species indicating the cold Labrador current. *Hyperia galba* (Montagu) and *Hyperia medusarum* (Müller) are presumably cold water species also. *Themisto abyssorum* (Boeck) in sizeable numbers is related to waters of the gulf of St. Lawrence, but does occur in very small numbers in the Labrador current. Both forms of *Themisto compressa* Goës are generally distributed in the area but are most numerous in the Labrador current. Of the gammarid Amphipoda, *Pseudalibrotus glacialis* Sars is an indicator of Labrador current water in the area. *Calliopius laeviusculus* (Krøyer), a surface swimming littoral form, is related to water of the gulf of St. Lawrence.

A new southern limit of distribution for *Pseudalibratus glacialis* is established. The species extends southward in the gulf of St. Lawrence to 49° 30′ north latitude. A new northern limit of distribution is given for the tropical genus *Phronima*, by the capture of a single immature specimen in Bradore bay, Quebec (51° 30′ north latitude).

The vertical distribution of certain hyperiid Amphipoda is correlated with light intensity. *Themisto libellula* and both forms (including very young stages) of *Themisto compressa* tend to be nearer the surface during daylight than during darkness. *Themisto abyssorum* tends to be nearer the surface during darkness than during daylight. *Themisto compressa* was taken in swarms at the surface during the early evening. This phenomenon is thought to be correlated with rapidly changing light intensity in the sea, immediately prior to the swarming.

Young and immature stages of *Themisto compressa* and *T. abyssorum* were very numerous at the surface, whereas adults of the same species were largely restricted to deep water usually some distance offshore. Abundance of the young of these species is a feature of the breeding season, part of which occurs during August and September in the Belle Isle strait region. The adult stage of *T. libellula* was not taken. *Hyperia* and *Hyperoche* were well represented by both adult and immature stages.

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Changes in Body Chloride, Density, and Water Content of Chum (*Oncorhynchus keta*) and Coho (*O. kisutch*) Salmon Fry when Transferred from Fresh Water to Sea Water

By Virginia Safford Black

Department of Zoology, University of British Columbia
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ABSTRACT

Changes in body chloride, density and water content of chum and coho salmon fry were measured when these fish were transferred from fresh water to sea water, and the reverse. Both species tolerated 50% sea water $(8-9^{\circ}/_{oo}$ Cl). Chum fry survived direct transfer from fresh water to sea water $(15-17^{\circ}/_{oo}$ Cl), but showed a marked increase in body chloride during the first 12 hours, followed by a return to the normal range between 12 and 24 hours. Coho, however, died within the first 36 hours, after a 60% increase in chloride. Coho fry lost more water than chum fry after introduction to sea water. The density of both species approximated that of the water within an hour of transfer to the new medium. When returned to fresh water after 12 hours in sea water the body chloride, density, and water content of both species regained normal levels within 10 hours. Chum salmon go to sea as fry, whereas cohos remain in fresh water a year or more. Although coho fry seem capable of some adjustment to sea water after a preliminary period in 50% sea water, permanent acclimatization could not be demonstrated under the experimental conditions.

INTRODUCTION

The ability of certain species of fish to migrate between fresh water and sea water has long been a matter of interest to fishermen and zoologists. Many of the morphological and physiological attributes which make such migrations possible have been described, but the whole picture is not yet clear. Knowledge of the subject at the present time has been reviewed recently by Black (1950) and Hoar (1950).

The experiments undertaken in this investigation describe the ability of chum (*Oncorhynchus keta*) and coho (*O. kisutch*) salmon fry to dispose of the chloride they absorb when transferred to sea water. In addition, analyses were made of fish which were returned to fresh water after a sojourn in sea water. The comparison of these two species is of special interest, because the chum salmon migrate to the sea soon after hatching, that is, at the time the experiments were being made, whereas the coho salmon remain in fresh water for a year or more before going to sea (Clemens and Wilby, 1946).

This work was carried out at the Cowichan lake hatchery on Vancouver island. At the time the hatchery was operated by the Pacific Biological Station, Nanaimo, under the direction of Dr. R. E. Foerster, to whom the author is

MATERIAL AND METHODS

All the chum salmon fry used were collected May 31, 1948, from the lower Cowichan river above tidal waters. These fish were kept during the summer in a hatchery trough which was continuously supplied with running water, 9.5 - 14.0°C. The coho fry were obtained periodically from the counting fence at Oliver creek near the hatchery. Water from this creek supplied the hatchery troughs. All fry in the hatchery were fed ground liver daily. Fry in experimental aquaria received fish meal, since the supply of sea water was limited and aquaria water could not be changed daily.

The transfer of fish to sea water, 50% sea water, or fresh water was always direct. The fish were not passed through intermediate salinities. The running water of the hatchery trough was used as a constant temperature bath for the experimental aquaria. Aquaria were aerated by a fine stream of bubbles.

To obtain the density of the salmon fry, 1 to 4 fish were placed in a 50 ml. glass-stoppered bottle filled with water from which the fish had come. The bottle was stoppered, carefully dried, and weighed on a chemical balance to the nearest milligram. The difference between this weight and the weight of the bottle filled with the water alone, was the weight of the fish in water. After the weight in water was taken the fish were dried by blotting with paper towelling and then weighed. The density was derived as follows:

$$\frac{\text{weight of fish in air} \times \text{density of water}}{\text{weight of fish in air} - \text{weight in water}} = \text{density of fish} .$$

The group of fish was then analysed as a unit for body chloride by means of Van Slyke and Sendroy's micromethod, as described in Peters and Van Slyke (1932).

A few measurements of dry weight were made in the following manner. The wet weights of the fish were made in the wide-mouthed tube (previously weighed)

used for chloride analyses. The fish were dried in these tubes for at least 12 hours at 100 - 120°C, then reweighed in the tube. Reagents for the chloride determinations were then added to the dry fish in the tube. Comparisons of the chloride content of dried and wet fish showed that no chloride was lost during drying.

RESULTS

I. *Control Fish*

Analyses of fish from the troughs were made almost every day. During the three months of the investigation the fry grew rapidly. Variation in size at any one time was more prevalent among the coho fry. The chum fry appeared to grow at a more uniform rate. This may be attributed to the fact that the chum were fed regularly in the hatchery after the initial collection from the gravel beds on May 31. The coho, on the other hand, were brought in periodically from Oliver creek, and some fry had doubtless been more fortunate than others in obtaining food, or had hatched earlier. Coho fry whose weights were recorded individually during the summer varied from 0.43 gm. to 3.12 gm., whereas the highest weight recorded for chum fry was 1.5 gm., the lowest, 0.44 gm. (average weight of 4 fish).

TABLE I. Average values for wet weight, body chloride, and density of control fish.

Date	Number of fish	Wet weight gm.	Body chloride milli-equivalents per kilo wet tissue	Density (Density of water—0.999)
1948 June 4 - 10				
Coho	36	0.41	45	0.998
June 24 - 30				
Coho	14	0.55	48	0.997
Chum	14	0.57	50	1.003
July 1 - 15				
Coho	51	0.70	48	1.000
Chum	70	0.63	51	1.006
July 16 - 31				
Coho	20	0.65	44	1.005
Chum	28	0.79	48	1.005
Aug. 4 - 6				
Chum	12	1.10	50	1.007
Aug. 21 - Sept. 5				
Chum	16	0.92	50	1.001

When the daily values for body chloride and density for chum and coho fry are plotted on a graph they are almost invariably a little higher for the chum than for the coho. Only two exceptions to this were found for chloride content and one exception for density, over a 21-day period. During this period a six-day cycle in rise and fall of body density was noticeable, especially in the chum. The significance of this is not clear.

It will be noticed that for the controls and for levels assumed by the experimental fish, the density of the fish is always higher than that of the water (table I). Lowndes (1938) terms this the "sinking factor" which he defines as the density of the fish divided by the density of the water. This extra weight provides the fish with a functional centre of gravity. Average values for weight, body chloride and density during the period of investigation are presented in table I.

After August 15 the chum fry in the hatchery trough started to die in considerable numbers; from 10 to 30 dead fish were removed from the trough each day until September 9 when all experiments were discontinued. At this time there were approximately 50 chum fry still living. Before death the chum tended to swim on their sides in a spiral path. Cohos were not affected in this way although the water supply was the same for all troughs in the hatchery. Analyses of dry weight and density made on chum from August 21 to September 5 differ significantly from those for fish taken previously. The density fell from an average of 1.007 in the latter part of July to 1.001; the percentage of water increased from 82.7 to 85.5. It is quite possible that these changes are associated with the migration to the sea which naturally occurs soon after hatching. A change in permeability of the tissues would result in a change in water content which might, in turn, affect the density of the tissues of the fish as a whole. A decrease in quantity and change of type of fat in young salmon has been reported by Lovern (1934). Hoar (1939) found that smolts of Atlantic salmon migrating to the sea were thinner than they had been as parr in fresh water. This decrease in fat could also change the water content of the tissues by altering their imbibition properties (Mayer and Schaeffer, 1914). All these changes may be related to the function of the thyroid gland, for Hoar and Bell (1950) found marked activity of the thyroid in the chum fry which had been retained in fresh water and in Atlantic salmon at the time of seaward migration. They believe that the increased activity of the gland is brought about because of greater metabolic requirements necessary for life in a medium (fresh water) which is no longer entirely suited to the physiological demands of the fish.

A few dry weights of control fish were measured and are recorded in table II. The chum appear to have a slightly higher water content (82.7%) normally than the coho (81.9%). It is interesting to note the tendency of the water content in the coho to decrease as the size of the fish increases.

II. *Fish Transferred Directly to 50% Sea Water* (8.5°/₀₀ Cl, 15°/₀₀ salinity, density 1.010)

Typical results are shown in fig. 1. During the first 12 hours there is a rise

TABLE II. Dry weights.

|	Number of fish	Weight gm.	Dry weight % of wet weight	% water content
Control fish		(average)		
Coho	2	0.49	16.3	83.7
July 20 - Aug. 6	2	0.87	17.6	82.4
	2	0.93	17.4	82.6
	2	0.94	18.3	81.7
	1	1.26	19.0	81.0
	1	3.22	22.0	78.0
		Average 1.28	18.4	81.6
Chum				
July 20 - Aug. 6	23	Range 0.8 - 1.32	16.8 - 17.7	82.3 - 83.2
		Average 1.02	17.3	82.7
Aug. 21 - Sept. 5	16	Range 0.7 - 1.2	13.4 - 15.5	84.5 - 86.6
		Average 0.92	14.5	85.5
Experimental fish July 20 - Aug. 6 Hours in sea water		(average)		
Coho 1.0	2	0.86	17.3	82.7
10.0	2	0.64	19.8	80.2
12.3	2	0.85	21.2	78.8
15.0	3	0.51	21.2	78.8
16.0	2	0.64	21.6	78.4
17.5	2	0.88	23.3	76.7
18.3	3	0.64	22.0	78.0
20.0	2	1.33	23.3	76.7
23.5	1	0.88	21.2	78.8
23.5	2	0.82	23.8	76.2
24.2	1	0.70	21.5	78.5
63.0	1	1.72	21.8	78.2
Chum 1.2	3	0.83	17.4	82.6
1.5	3	0.69	17.5	82.5
3.5	3	0.87	17.8	82.2
5.5	3	0.79	17.5	82.5
7.8	3	0.89	18.6	81.4
9.8	3	0.74	17.4	82.6
11.3	3	0.91	18.8	81.2
11.5	3	0.75	18.1	81.9
23.0	3	0.93	17.1	82.9
23.0	3	0.87	17.4	82.6
42.5	3	0.98	17.6	82.4
73.8	3	0.83	16.6	83.4
84.0	3	0.70	16.6	83.4
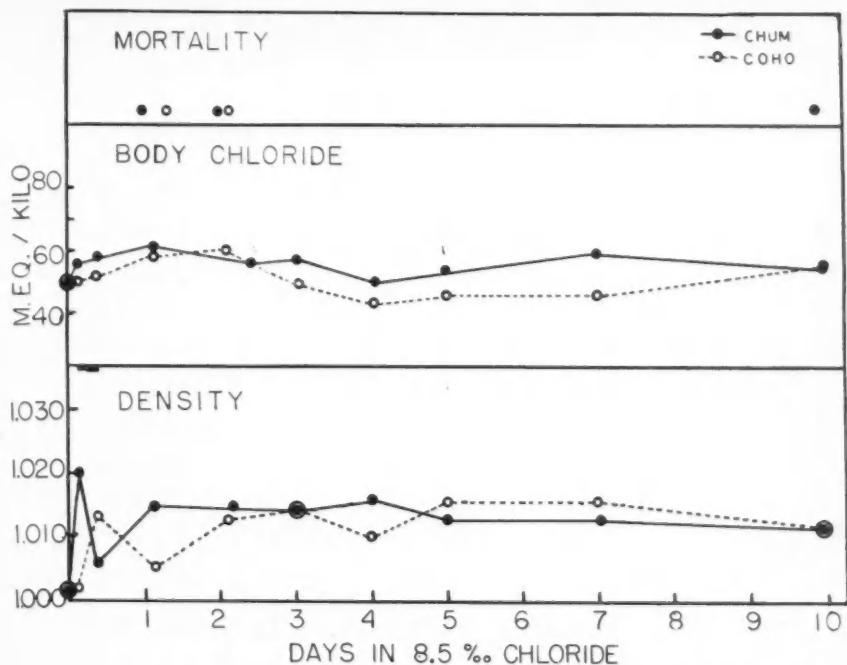
FIGURE 1. Changes in body chloride and density of fish after transfer from fresh water to 50% sea water (8.3 - 8.8°/oo Cl).

in density of the fish to a density higher than that of the water. The density falls lower than water density after about one day and then increases again, more gradually, to a permanent level somewhat higher than that of the water.

Analyses of body chloride show a small but significant rise during the first two days and then level off again near the normal value.

Mortality in this series consisted of 1 coho at 32 hours, 1 at 48 hours; 1 chum at 24 hours, 1 at 48 hours, and 1 after 10 days. Approximately 70 fish of each species were transferred so that mortality was low for both the coho and chum in half sea water.

The data presented in fig. 1 indicate that the response of both species to 50% sea water is similar but that the coho fry react more slowly than the chum fry.

III. *Fish Transferred Directly to 100% Sea Water* (15 - 17°/oo Cl, 27 - 31°/oo salinity, density 1.019 - 1.022)

Within an hour the density of both species increased to become equal to or higher than the density of the water. A decrease in the density of the fish followed and, in the chum, finally levelled off slightly above the water density. Mortality in the coho made observations after a 24-hour period impossible.

Body chloride increased in both species during the first 12 hours at approximately the same rate. Between 12 and 24 hours the chloride content of the chum fry decreased to near normal and the fish appeared to be able to survive indefinitely in the sea water. The coho, however, with only two or three exceptions were dead after 24 hours in sea water. The increase in tissue chloride in both species was more rapid in $17°/_{oo}$ Cl (from 50 to 78 m.eq. Cl per kilo in 6 hours) than in $15°/_{oo}$ Cl (from 50 to 64 m.eq. Cl per kilo in 6 hours). In the stronger sea water the chum fry returned to 62 m.eq. Cl per kilo and maintained this level over a 10-day period; in the weaker sea water the normal level of 50 m.eq. Cl per kilo was regained. The results for the latter series are shown in fig. 2.

Mortality of chum fry was light, and always occurred between 9 and 12 hours. In four series such as the one shown in fig. 2 only 6 fish died. It will be seen by referring to fig. 2 that death occurred near the peak of tissue chloride. The fish apparently could not dispose of the chloride absorbed from the sea water before
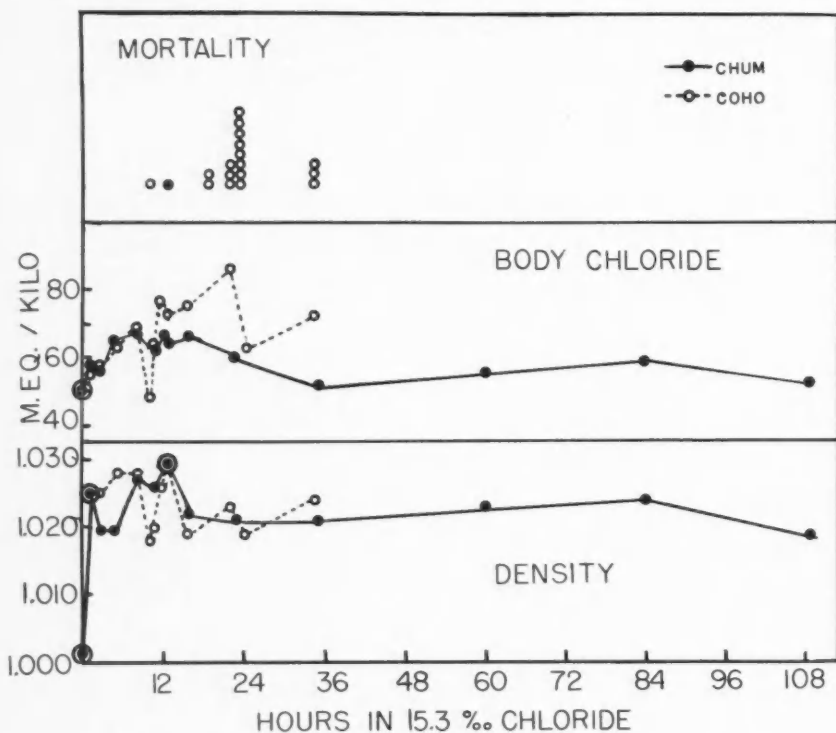

FIGURE 2. Changes in body chloride and density of fish after transfer from fresh water to sea water ($15.3°/_{oo}$ Cl).

death occurred. Among the coho mortality was almost inevitable. Most of the series were started in the morning and no mortalities were recorded before 9 hours, but all the fish would be dead the following morning. One series, started at night and followed the next day, indicated that the highest mortality occurred between 17 and 20 hours. A mortality experiment done early in September on fish about 1 centimetre longer than those previously used resulted in 9 dead within 2 days, the 7 remaining fish appeared in good condition at $2\frac{1}{2}$ days, after which time the experiment had to be discontinued. In December, 6 cohos were put in sea water ($15°/_{oo}$ Cl) and 5 (5.6 - 6.3 cm) died between the second and fourth days. The sixth fish, also the largest (7.1 cm), succumbed on the sixth day. This increased viability in September and December may be the result of larger size. Huntsman and Hoar (1939) found that large Atlantic salmon parr survived longer in sea water than small fish. In the eight mortality series made from June to December, 1948, there was a tendency for the smaller fish to die first, but there were many exceptions. Hoar (1949) was unable to find a correlation between size and survival of coho fry in sea water.

A few dry weight determinations were made on coho and chum fry after transfer to sea water. These are summarized in table II. The table shows that coho fry in sea water lose water from the tissues, whereas values for chum fry do not differ significantly from the controls analysed at the same time. The two groups of chum at 11 hours and one group at 8 hours show a slight decrease in water content. It will be recalled that at this time the chloride content of the chum is greatest, that is, regulation with respect to salt has not yet occurred. Regulation of water content is probably also deferred several hours as was found to be the case for the eel (Keys, 1933) and killifish (Black, 1948) transferred from sea water to fresh water.

IV. *Return to Fresh Water after Twelve Hours in Sea Water* ($17°/_{oo}$ Cl)

In fig. 3 curves are plotted which indicate that chum and coho fry recover quickly when transferred from sea water to fresh water at the height of chloride gain (12 hours, fig. 2). Density decreases within 3 hours and may fluctuate considerably thereafter, but attains the normal for fresh water within 24 hours. The body chloride content decreases to normal within 10 hours. Dry weights have also been plotted and indicate a gain in water content for both species though the change is more marked in the coho.

A few chum fry were returned to fresh water after $3\frac{1}{2}$ days in sea water. There was no significant change in the tissue chloride of these fish, since they had already regained their normal chloride level (fig. 2). The density decreased from 1.026 to 1.012 within 1 hour. The water content increased from 83.4% to 84.6% within 2 days and was 84.7% on the third day.

One coho died between 48 and 64 hours after return to fresh water, and 2 chum fry were dead after 29 hours. The dead chum fry showed a lower tissue chloride (38 m.eq./kilo) and higher water content (84.6%) than live fish taken
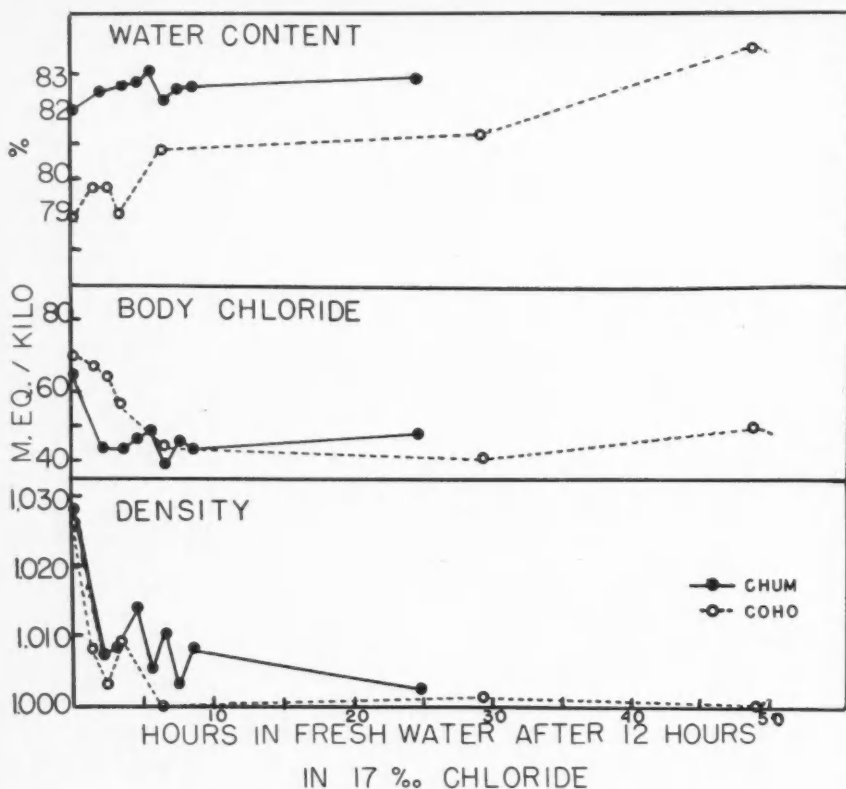
FIGURE 3. Changes in body chloride and density of fish returned to fresh
water after 12 hours in sea water ($17°/_{oo}$Cl).

at the same time (47 m.eq. Cl/kilo, 82.9% water). Two other series using chum
fry showed no mortality.

A comparsion of rate of adjustment to sea water (fig. 2) and of readjustment
to fresh water (fig. 3) indicates that the latter takes place more readily. It was
found that the return to the natural environment (sea water) in the killifish also
proceeded more rapidly with respect to body chloride and density (Black, 1948),
than the original transfer to fresh water.

V. *Acclimatization in 50% Sea Water (8.8°/_{oo} Cl) before Transfer to Sea Water
(17°/_{oo} Cl)*

This experiment involved placing a number of fish in an aquarium of half sea
water. Each day thereafter for 10 days a group of 2 to 6 fish was transferred to
sea water and allowed to remain there for 24 hours. At the end of this time the

chloride and density of the fish were determined. The results of these analyses are presented in fig. 4.

The density (1.020 - 1.034) of the fish in these experiments does not seem to show any particular trend. The density of the cohos is higher than would be expected from fig. 2 (15.3°/₀₀ Cl). Even a difference of 2°/₀₀ Cl must be significant in the adjustment of the fish, because two other series (not shown by graph) in the weaker sea water (15.3°/₀₀ Cl) gave much lower densities (1.012 - 1.024) and slightly lower chloride values.

The body chloride of both species after 1 day in sea water decreases as the previous time spent in half sea water increases. After 6 days in the aquaria, however, the results are variable not only for the coho but also for the chum. This may mean that the condition of the fish deteriorated in the aquarium due to insufficient food supply or some other factor. A similar situation prevailed in the acclimatization of the killifish to fresh water (Black, 1947). It appears from fig. 4 that 6 days of acclimatization results in a decrease of approximately 10 m.eq./kilo in the chloride taken on by the fish after 1 day in sea water.
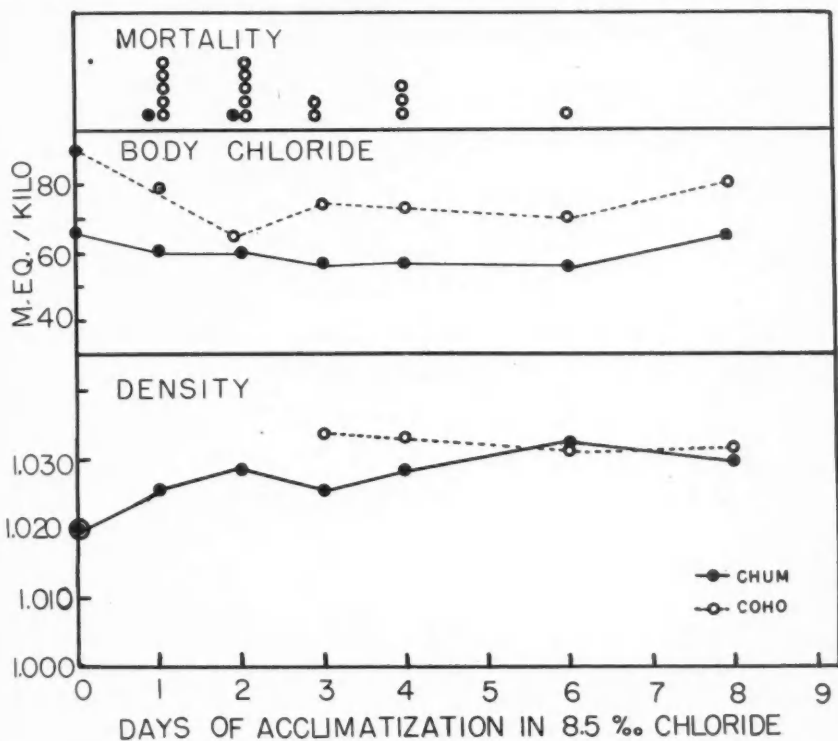
FIGURE 4. Body chloride and density of fish after 24 hours in sea water (17°/₀₀ Cl). These fish were acclimatized in 50% sea water as indicated on the abscissa.

Decrease in mortality after acclimatization is especially significant. Mortality among chum fry was low; among the coho, mortality decreased as the previous time spent in half sea water increased.

Acclimatization in 50% sea water appears to be beneficial in these experiments, but the results do not indicate how permanent such acclimatization may be.

DISCUSSION

The results obtained in these experiments give a measure of some of the physiological differences between the chum salmon fry which are ready to go to sea and the coho fry which spend a year in fresh water before migrating seaward. Although none of these experiments deals with the actual mechanisms involved in osmotic regulation in these fish, an interpretation of the results may be made on the basis of present knowledge of osmotic regulation in teleost fishes.

I. *Changes in Body Chloride*

The increase in chloride content as a result of transfer from fresh water to sea water may be caused not only by the diffusion of salts through semi-permeable tissues, but also by the concentration of the salts present because of loss of water. The mortality occurring in sea water appears to result from the accumulation of salts in the tissues, but the specific cause of death was not determined.

The return of body chloride of the chum fry to normal within 36 hours after transfer to sea water is the most significant difference found between the chum and coho fry in these experiments. The mechanism for the excretion of salts can function efficiently in the chum fry before the tissues attain a lethal salt concentration. Cells responsible for the excretion of chloride in the gills of marine fish have been described by Keys (1931) who termed them "chloride secreting cells". Although the presence of these cells in the gills of chum salmon fry has not yet been certified, Hoar (1948) has found cytological differences in the gills of chum and coho fry. According to Hoar large acidophilic cells are typically found at the bases of the gills of chum and pink salmon in sea and fresh water, whereas similar cells do not appear in the gills of coho salmon until the beginning of the second year, that is, when the coho migrate to the sea. Both chum and pink salmon migrate as fry in their first year. It seems probable, therefore, that the presence of functional "chloride secreting cells" is largely responsible for the ability of the chum fry to adjust themselves to sea water.

The ease with which both species became adapted to half sea water may be explained partly by the fact that the concentration of the external environment (8°/$_{oo}$ Cl) was only slightly higher than that of the body fluids, 6°/$_{oo}$ Cl ($\Delta -0.63°C$, Greene 1904, for adult spring salmon, *Oncorhynchus tschawytscha*, in fresh water). Apparently even the coho are able to cope with this concentration difference by normal physiological activity. Goldfish are also able to live in half sea water for a week or more (Pora, 1939; Black, 1949).

The return of body chloride to normal levels in fish returned to fresh water (fig. 3) may be accounted for by the outward diffusion of excess salts. The "chloride secreting cells" of the chum fry may assist in salt excretion at this time.

II. *Changes in Density*

When the fish are transferred from fresh water to a more concentrated environment (figs. 1 and 2) they are less dense than the new medium and hence tend to remain at the surface until some adjustment is made. Several coho were observed constantly during the first hour after transfer, and at intervals bubbles were seen to escape from the mouth. It was assumed that this gas came from the air bladder. With the emission of gas the fish became less buoyant and were able to assume positions in the middle and lower areas of the aquarium. Loss of body water by osmosis (table II) probably also helped to increase the density of the fish.

When, however, the fish are returned to fresh water (fig. 3) they are more dense than the water and sink to the bottom, unless strenuous swimming efforts are made. In this situation fish become less dense by gulping air and by osmotic intake of water through semi-permeable membranes. Fluctuations in density following the initial fall may be due to kidney function; the water acquired osmotically would be excreted periodically by the kidneys, thus increasing the density slightly at the time of excretion.

III. *Changes in Water Content*

Although not many dry weight determinations were made, the data in table II indicate that water loss is much greater in coho fry after transfer to sea water than is the case for the chum fry. The latter show only a slight loss between 8 and 12 hours. Osmotic and mechanical differences may be responsible for the results. The permeability characteristics of the tissues may be specific, coho tissues being more permeable to water than chum tissues. Another explanation lies in the ability of the fish to swallow sea water. It is well known that marine fish maintain their water content by swallowing sea water and excreting the salts by way of faeces, urine, and gills. Perhaps the coho did not drink any sea water whereas the chum did. Henschel (1936) showed that one reason why two species of flounder (*Pleuronectes*) differed in tolerance to diluted sea water was that the more resistant species (*flesus*) was able to stop drinking water while the sensitive species (*platessa*) continued to drink in spite of the osmotic inflow of water through gill and oral membranes. Another important factor in water balance is urine secretion. A decrease in volume of urine excreted when in sea water would prevent water loss. The experiments do not, however, show the extent to which these various factors operate in the water balance of the chum and coho salmon fry.

The gain in water by fish returned to fresh water at the time of greatest water loss (12 hours) is plotted in fig. 3. Probably most of the water was acquired by

osmosis through the membranes of gills and oral cavity. It is interesting to note that the slight decrease during the general rise in water content in each species corresponds with an increase in density. This seems to confirm a relation between water content and density. Loss of water by urine excretion may explain the small decreases in water content and increases in density in both species.

IV. *Acclimatization*

Acclimatization to sea water occurs readily in chum salmon fry for reasons discussed above. Unfortunately the scope of the experiments on acclimatization of coho fry to sea water is not sufficient to warrant a definite conclusion. Although acclimatization of coho fry in half sea water for several days before transfer to sea water appeared to decrease mortality and chloride gain, the conditions of the experiment did not permit observations over longer periods of time.

Current investigations and theories concerning migration of fish (Fontaine, 1943, 1948; Koch and Heuts, 1942, 1943; Hoar and Bell, 1950) have dealt with hormones as the agents active in causing migrations and also the physiological and morphological changes necessary for survival in the new environment. Although hormones may be influenced somewhat by environmental conditions, changes in hormone activity are usually correlated with growth and development of the individual. If hormones are largely responsible for the necessary physiological changes during migration, it seems doubtful that gradual acclimatization alone could cause permanent and successful adjustment of the coho fry to sea water during the first year of life.

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A Study of the Skeena River Climatological Conditions with Particular Reference to their Significance in Sockeye Production

By J. R. Brett

Pacific Biological Station
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ABSTRACT

From an analysis of climatological conditions in the Skeena river watershed no climatic variations or cyclic trends which might account for a declining sockeye fishery have been detected.

Most of the area in which sockeye spawn has an annual rainfall of less than 20 inches. A significant relation between sockeye production and rainfall in the spawning months of August and September was apparent for the years 1920 to 1934. While successful prediction cannot be anticipated, conservation through stream-level control is supported.

INTRODUCTION

In view of a declining return in the commercial salmon pack of the Skeena river an investigation of the biological and physical features of the system was commenced in 1944 (Pritchard, 1947). The specific aim of the investigation was to obtain information for management or conservation of this natural resource, particularly the most valuable species, sockeye salmon (*Oncorhynchus nerka*). The following questions were considered pertinent to the problem:

1. What are the climatological characteristics of the Skeena river drainage?

2. Has there been any significant change in climate during the period for which records are available?

3. Is there a cyclic nature to the climatological fluctuations, particularly in four to six year periods?

4. Do the variations in climate, annually or seasonally correspond in any way to the variations in production of sockeye, either throughout the area or in any particular zone?

In consequence a study was made of the climatological conditions of the Skeena river drainage from records presented in "Climate of British Columbia" (1945). These records, published in this form from the first edition in 1912, include a constantly increasing number of observational stations in later years. Within the area of the Skeena river drainage there exist 7 stations which report for 12 months of the year, and 1 which operates during the spring and summer months only (fig. 1). These stations and the periods of operation are listed from west to east in table I, to which has been added one outside station, Fort St. James, from which records for the extreme eastern territory have been used. This station is not more than 21 miles beyond the eastern extremity of the Skeena river

TABLE I.   Meteorological stations, their location and period of
operation in the Skeena river drainage.

Station	Period of Operation	Location
Prince Rupert	1909-1948, complete year	54° 30′ N., 130° 20′ W. On the coast.
Lakelse lake	1932-1935 " " 1946-1948 ½ year	54° 22′ N., 128° 31′ W. 71 miles east of the coast.
Rosswood	1928-1948, complete year	54° 50′ N., 128° 45′ W. 74 miles east of the coast.
Terrace	1913-1948 " "	54° 30′ N., 128° 40′ W. 75 miles east of the coast.
New Hazelton	1915-1948 " "	55° 20′ N., 127° 40′ W. 133 miles east of the coast.
Smithers	1940-1948 " "	54° 34′ N., 127° 15′ W. 134 miles east of the coast.
Telkwa	1923-1948 " "	54° 40′ N., 127° 5′ W. 136 miles east of the coast.
Babine lake	1917-1934 " " 1945-1948	55° 15′ N., 126° 25′ W. 176 miles east of the coast.
Fort St. James	1894-1948 " "	54° 35′ N., 124° 20′ W. 229 miles east of the coast.

drainage in the vicinity of Babine lake and almost exactly 40 miles from the south-
eastern tip of the lake itself.   The first of these stations listed, Prince Rupert, is
not within the actual drainage basin, but is sufficiently close to be as valuable as
any other locality on the coast for the purpose of this study.

CLIMATOLOGICAL CHARACTERISTICS OF THE SKEENA RIVER DRAINAGE

The Skeena river drains an area of approximately 19,300 square miles,
extending from the Pacific coast on the west to an extreme eastern point of
drainage in the headwaters of the Sutherland river, a tributary of Babine lake
(fig. 1).   The distance between these two points is approximately 220 miles, while
that from the northern extreme is just short of 245 miles.   It is centrally located
in British Columbia with its tributaries extending eastward beyond the midpoint
of the province.   A marked diversity in climate exists throughout the area,
varying from moderate temperatures and heavy precipitation on the coast to
extremes of temperature with periods of almost rainless months east of the Coast
Range mountains.   Aside from the northern location, mainly between 54° and
57° N. Lat., three of the major factors affecting the climate are (1) the warm
North Equatorial Current, a part of which swings north at approximately 40° N.
Lat., sweeping up the coast and continuing north-westward in Alaskan waters,
(2) the broken and rather scattered *Coast Range* mountains with the Babine
mountain range sheltering the largest lake in the system, and (3) the gradual
rise in height of land which results in the majority of the drainage area being over
2,000 feet above sea level, e.g., Babine lake, 2,300 feet; Morice lake, 2,600 feet.

FIGURE 1. Map of the Skeena river showing positions of meteorological stations.

Lines joining points of equal temperature and equal precipitation almost invariably run in a northwest, southeast direction where they pass through the Skeena river territory and consequently parallel to the general line of the coast. The differences in climate therefore run at right angles across these lines, in a northeasterly direction.

During the summer the difference in average monthly *temperatures* from west to east is not great. It is maximal at Terrace with 62°F. in August, and between 56°F. and 58°F. at all other recording stations. The greatest difference in these average temperatures occurs in the month of January at which time there is an almost constant decrease at the rate of 13.5°F. per 100 miles northeast across the Skeena area. At Prince Rupert the January average is 3°F. above freezing, while that for Fort St. James is 22°F. below freezing. Such averages take no

account of variations from day to day which also increase from the coast inland
with increased distance from the moderating effect of the ocean. Prince Rupert
in 1945 showed a difference in August extremes of high and low temperatures of
37°F., Terrace 57°F. and Telkwa 59°F., while those in January varied as much
as 50°F. in New Hazelton and 30°F. in Terrace, with only an 18°F. variation at
Prince Rupert. Fort St. James showed an extreme difference of 62°F. in January
of 1945.

The average annual *precipitation* drops rapidly from a high of nearly 100
inches on the coast to nearly one-half of that at Terrace, levelling off at slightly
less than 20 inches annually within 125 miles of the coast (table II). Where the
rainfall is high there is a distinct low period in the late spring and summer months,
but where it is low (for example, Babine) it rarely passes above a monthly average
of 2 inches nor below 1 inch throughout the year.

TABLE II. Average annual precipitation for periods
of operation at each of the meteorological
stations in the Skeena drainage.

Station	Annual average
Prince Rupert	95.34 inches
Rosswood	31.69 "
Terrace	46.85 "
New Hazelton	18.73 "
Telkwa	15.55 "
Babine Lake	18.94 "
Fort St. James	15.61 "

Approximately 75% of the drainage area is over 100 miles from the coast.
Present observations indicate that the final distribution of sockeye on the spawn-
ing beds is in about the same ratio. The fish bound for the Nanika river in the
Morice lake system, however, must first pass well inland via the Skeena river,
branching off in the Bulkley and returning westward to come just less than
100 miles from the coast at their final destination. With the addition of this run
nearly 90% of the sockeye experience river conditions of the area which is over
100 miles inland. It is the climate of this region that will exert the major effect
on sockeye production in those instances when climate does play a distinguishable
role.

To sum up, the climate of the Skeena river varies from the coast inland
changing rapidly from the moderate temperature and heavy precipitation near
the ocean to more extreme temperatures and less precipitation as the limit of the
eastern side of the Coast Range mountains is approached. Beyond 100 miles
from the coast a relatively extreme climate is characteristic of the area. The
rainfall rarely exceeds 2 inches per month at any time, and although high tempera-
tures are infrequent, possibly because of the northern location and the general

elevation of the country, extremes of low temperature occur. In brief it is a comparatively dry, extreme climate.

CONSTA.. CY OF CLIMATE

Any series of records of climatic conditions will usually show odd variations of an extreme nature. In 1939 there was an exceptionally heavy rainfall in the Skeena river district and elsewhere in northern British Columbia, but no continuous variation has been detected to demonstrate any change in the general climatic conditions.

The annual *precipitations* recorded since 1916 for all stations from Prince Rupert to Fort St. James show no significant variation above or below the mean at any one period of time. A similar statement can be made for the annual *temperature* averages for this period. A further analysis of the temperature records was made to determine whether the monthly means were changing, that is, more extreme in summer and winter, yet producing the same yearly mean. There does not appear to be any indication that such is the case from a study of the Terrace and Fort St. James records. Successive five-year periods were averaged in each month for Terrace and compared in their differences from the monthly mean for 20 years. No significant trend or variation was discovered. For Fort St. James there is a 5°F. increase in the average monthly temperatures in January and February for the five-year period 1941 to 1945 over the 52-year average, but not to the same degree in other months. This is not sufficient to be of concern from the point of view of salmon production since it is a tendency toward moderation in the winter period.

CYCLIC TRENDS

Between four and six years from every peak in the Skeena sockeye catch there has occurred another peak (1909 to 1947). These peaks have occurred twice 4 years apart, three times 5 years apart and twice 6 years apart. The precipitation and temperature tables have been studied closely for an indication of any such trends, or cyclic fluctuations of a greater or lesser extent. For the period investigated and from a consideration of monthly averages, weekly averages, extremes of high and of low rainfall in each of the meteorological stations, no indication of cyclic trends of any duration was apparent. The answer to the question of such trends, particularly in precipitation, which appears to be of marked importance in relation to salmon production (cf. Hagman, 1938), is distinctly a negative one.

CLIMATIC CONDITIONS CORRELATED WITH SOCKEYE PRODUCTION

If no one factor, such as spawning escapement reduced to insignificance in relation to catch and thereby completely masking any other relation, is dominant in limiting sockeye production, then it appears that the production is the result of an integration of many influences. For climatic conditions and their effect on

salmon production it is analogous to the returns from a field of grain which, if sown under ideal conditions and ripened with the same perfection, will result in maximum crop. Adversities of climate can be catastrophic if they coincide with critical times of development. Likewise a low efficiency of production from a given salmon escapement may be the result of drying up or reduced flow in streams, extreme temperature conditions at spawning time, or sudden freshets washing out spawning beds. The factors which appear to hold promise as being the most reliable indices of the efficiency of returns for salmon in certain areas of the west coast are the rainfall in the months of August and September (*O. nerka*) and the stream discharge in the late months of the fall (*O. keta*). These relations have been demonstrated with some success for streams with spawning areas in close proximity to the ocean by Neave and Wickett (MS.). With this instance and stimulus the months of August and September were singled out for a study of the relation between precipitation and sockeye production in the Skeena drainage. The biological significance of these months can be attributed to the relation between rainfall and stream levels during the main spawning period of late August and September. Below average rainfall at this time of year means below average stream levels and consequent reduction of the area of spawning grounds. Increased competition for spawning beds and superimposition of eggs would mean reduced efficiency of hatch.

The production of sockeye which resulted from given spawnings in the years 1920 to 1940 is plotted in fig. 2A. Each year shows the total in 4_2, 5_2, 5_3 and 6_3 age groups which was obtained in the commercial catch in the succeeding 4, 5 and 6 years following the year of egg deposition (Clemens, 1946). It is what was produced in the commercial catch by the seeding of a given year. This has been termed the "production". To be more precise it should include what was "produced" in the escapements, but accurate numerical records are not available for this latter figure. The assumption has been made that the returns to the commercial fishery are indicative of the total success of the product. There is a distinct possibility of error here, since there is little relation between catch figures and corresponding escapement estimates (coefficient of correlation $= + .38$). This may be the result of inaccuracies of reports on spawning grounds. An attempt has been made to assess the spawning ground reports submitted in the annual "Report of the Commissioner of Fisheries" and to evaluate the escapements. These data and those for the catch and production records appear in fig. 2.

If the rainfall in August and September affects the efficiency of egg deposition then the relation beween seeding and precipitation should be apparent in the resulting production. The most appropriate figure on precipitation is problematical, for although an estimated 75% of the spawning occurs beyond the 100 mile line from the coast, and this zone is of a fairly uniform climate, there are sufficient dissimilarities between precipitation records for the same years from the different meteorological stations to introduce only a partial representation of the area by using the observations from a single station. In the years 1920 to 1940 the per
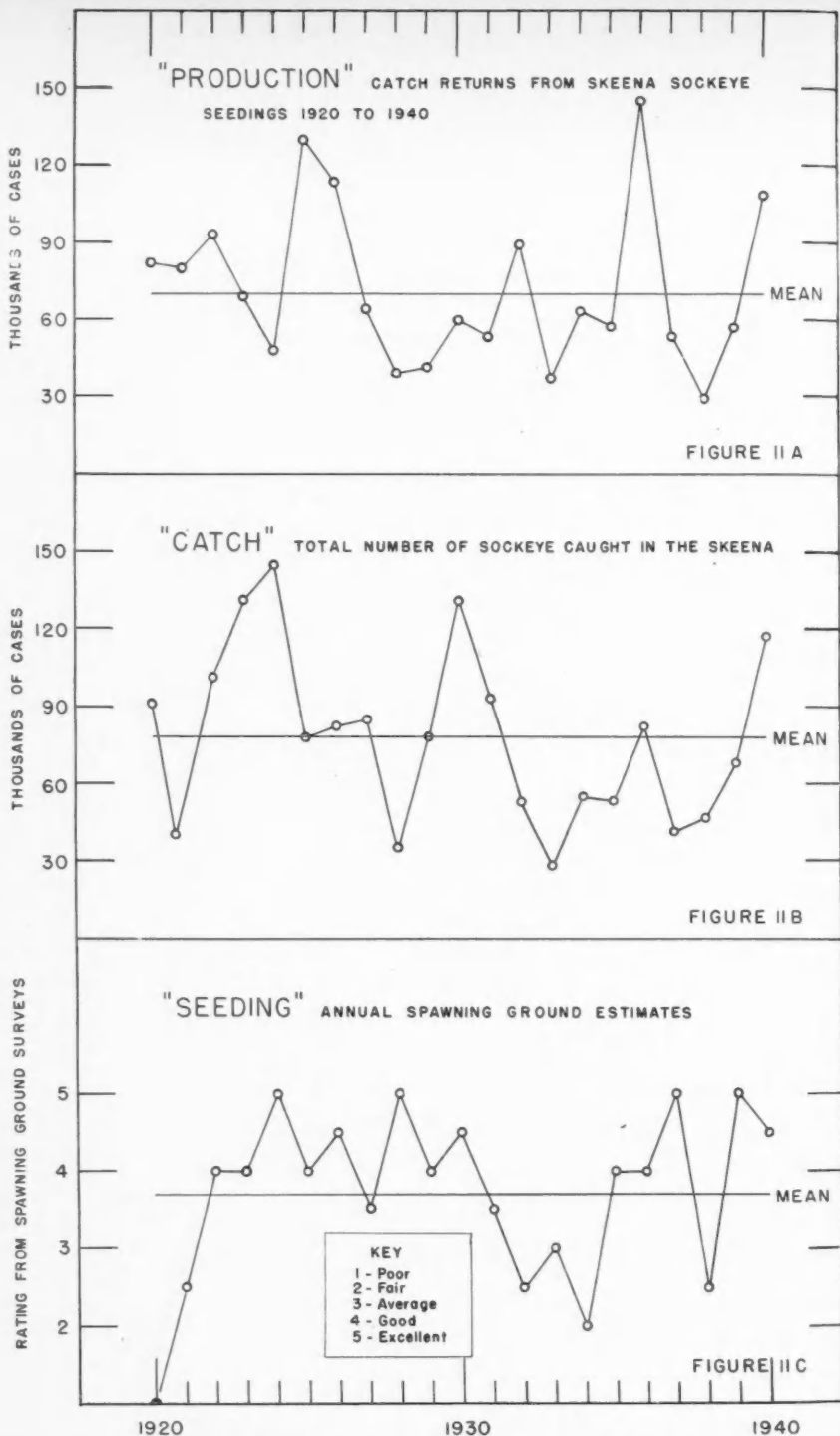
FIGURE 2. The production, catch and seeding of sockeye on the Skeena river, 1920 to 1940. The production recorded for 1920 is the total of the fish caught from the seeding of 1920.

cent occurrence of the corresponding total precipitations for August and September on the same side of the mean was 71 for New Hazelton and Babine, 79 for Babine and Fort St. James and only 52 for New Hazelton and Fort St. James. Only the records for Babine have been used since the best approximations to date credit the Babine area with over 66% of the total spawning for the whole system.

TABLE III. The catch, production, precipitation (Babine only) and seeding records for 1920 to 1934.

Year	Catch (1000's of cases)	Variation from mean (multiples of standard deviation)	Production (1000's of cases)	Variation from mean (multiples of standard deviation)	Precipitation (inches)	Variation from mean (multiples of standard deviation)	Seeding* (5-point scale)	Variation from mean (multiples of standard deviation)
1920	91	+0.27	72	+0.18	6.89	+2.34	1.0	−2.30
1921	40	−1.21	70	+0.10	3.71	+0.21	2.5	−0.94
1922	101	+0.55	83	+0.61	2.43	−0.65	4.0	+0.43
1923	132	+1.45	69	+0.06	4.42	+0.68	4.0	+0.43
1924	145	+1.83	48	−0.76	3.44	+0.03	5.0	+1.34
1925	78	−0.11	130	+2.44	5.78	+1.59	4.0	+0.43
1926	82	+0.01	113	+1.78	3.93	+0.35	4.5	+0.88
1927	84	+0.07	62	−0.21	3.75	+0.17	3.5	−0.03
1928	35	−1.35	35	−1.27	1.53	−1.25	5.0	+1.34
1929	78	−0.11	40	−1.07	1.32	−1.38	4.0	+0.43
1930	131	+1.43	60	−0.29	1.37	−1.36	4.5	+0.88
1931	93	+0.32	53	−0.57	2.36	−0.70	3.5	−0.03
1932	53	−0.83	79	+0.45	3.23	−0.11	2.5	−0.94
1933	28	−1.55	37	−1.19	3.30	−0.07	3.0	−0.48
1934	55	−0.77	63	−0.18	3.59	+0.13	2.0	−1.39
Mean:	81.7		67.5		3.40		3.53	
Standard deviation:	±34.6		±25.6		±1.49		±1.10	

*Determined from estimates arranged in a 5 point scale: 1 = poor; 2 = fair; 3 = average; 4 = good; 5 = excellent.

To determine whether any significant relation could be traced between the four variates (seeding, precipitation, production and catch), the data for the fifteen-year period, 1920 to 1934, have been analysed (table III). These are the years in which precipitation records are available for Babine lake. In order to compare variation of catch in thousands of cases with precipitation in inches and seeding estimates on a point scale, the variation has been expressed in terms of the separate standard deviations for each group of records, that is, in any one year the extent to which a given observation differs from its fifteen-year mean has been expressed as a multiple of its standard deviation (table III). In this manner it

has been possible to compare these different type observations taking into account the variability within each category. These values have been used in working out the correlation coefficients that are listed in table IV.

TABLE IV.   Coefficients of correlation for seeding (1), precipitation (2), production (3) and catch (4).

Variates	Correlation coefficients	Significance level	
		P .05	P .01
Seeding × Precipitation	$r_{12} = -.54$	.51	.64
Seeding × Production	$r_{13} = -.04$	.51	.64
Seeding × Catch	$r_{14} = +.38$	.51	.64
Precipitation × Production	$r_{23} = +.56$	.51	.64
Precipitation × Catch	$r_{24} = +.04$	.51	.64
Production × Catch	$r_{34} = +.10$	.51	.64
Seeding × Production (Precipitation constant)	$r_{13\cdot2} = +.37$	.53	.66
Precipitation × Production (Seeding constant)	$r_{23\cdot1} = +.64$	.53	.66

The only correlation within the P. 01 level of significance is that for the partial correlation between precipitation and production with seeding held constant ($r_{23\cdot1} = +.64$). A further study of the correlation coefficients shows that there is no correlation between seeding and production ($r_{13} = -.04$) but that this relation is altered if precipitation is held constant giving a partial correlation of $r_{13\cdot2} = +.37$. Although this does not bring the relation within even a P .05 significance level it serves to demonstrate the possible importance of precipitation. One reason why seeding shows no relation to production for these data can now be traced to the negative correlation between seeding and precipitation. The extent to which these latter fall on opposite sides of their respective means in the same year is within the P .05 significance level ($r_{12} = -.54$). At present there is no obvious explanation for this latter correlation. Close inspection of conditions on the spawning grounds and of the effect of high water on the presence of mature sockeye may provide some explanation.

DISCUSSION

The biological interpretation of these data is that rainfall during the months of August and September can have sufficient effect on the success of egg survival to show a significant return in the subsequent commercial catches (production). Although no significant relation exists between estimates of seeding and production it must be recognized that this is only true where sufficient eggs have been deposited to permit water conditions to have such a perceptible influence. If there were no eggs, precipitation could hardly be of importance. It will be noticed that the two outstanding years of production, 1925 and 1926, were years in which *both* seeding and precipitation were distinctly above average.

The best test of these data would be to use the technique for prediction of future production. Unfortunately this cannot be done for the next few years

since the meteorological station at Babine has only recently commenced to operate again. It is also not feasible for predicting catch since there is not sufficient constancy to, nor any known method of prediction for the relation of the different age groups. The average occurrence (1920-40) of 4_2, 5_2, 5_3, and 6_3 sockeye in the commercial catch has been 50%, 35%, 11% and 4% with a great deal of variation in each class. Each year's forecast would have to stem from predictions of production for a series of three years (4, 5 and 6 year old fish) modified by the knowledge of occurrence of 4 and 5 year old fish which had been the product of the same seedings in previous year's catches, for example, if the prediction from the seeding in 1944 was a 50% above average production, it could bear fruit in 1948 mainly as 4_2's, or in 1949 as 5_2's. The different age groups turning up inconsistently in the catch add a disconcerting perplexity to the problem of prediction.

While these relations must be tempered by a reiteration of the lack of absolute reliability that can be attached to seeding estimates, catch records and age determinations, they do lend support to the thesis of conservation through stream control. If the major spawning streams could be maintained at a level which was not less than when precipitation was average in August and September it would appear that the production might increase by a measurable amount.

SUMMARY

1. The climate for the area of the Skeena river drainage which is 100 miles or more from the Pacific coast and in which approximately 75% of the sockeye spawning occurs, is relatively extreme. The rainfall averages slightly less than 20 inches per year, and January temperatures average as low as 10°F. at Fort St. James.

2. There has been no change in the climate of apparent significance in sockeye production for the period 1920 to 1940.

3. No cyclic trends appear in the average temperature or precipitation records throughout the last 30 years.

4. For the years 1920 to 1934 there is a significant relation between precipitation in the spawning months of August and September and production of sockeye in the commercial catch returns with seeding held constant. (Partial coefficient of correlation $= + .64$; $P.01 = .66$.)

5. Prediction cannot be made from these relations.

6. Stream water-level control should result in a measurable increase in sockeye production.

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